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# THE EFFECT OF VARYING TRAINING RESISTANCE ON THE FORCE-VELOCITY RELATIONSHIP AND POWER OUTPUT


by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled THE EFFECT OF VARYING TRAINING RESISTANCE ON THE FORCE-VELOCITY RELATIONSHIP AND POWER OUTPUT submitted by DONALD F. MATTERN in partial fulfilment of the requirements for the degree of Master of Science in Physical Education.

ABSTRACT

The purpose of this study was to investigate the affect or varied resistance training on the force-velocity relationship and power output. Two sub-purposes were; a) to determine if the difference between training programs affected muscle restitution and, b) whether there was a difference in the affect between skilled and unskilled subjects.

Twenty-eight males participated in the study. One training group trained with a uniform heavy resistance every day, a second group varied the resistance from day to day and a third group acted as the control. The training groups performed six sets of five leg extensions for five days per week for six weeks.

The results indicated that there was no difference in power output between the two training groups from pre-test to post-test. The differences in force output and velocity between groups indicated that they were training on different segments of the force-velocity curve.

Muscle restitution was not affected by either training program.

Unskilled subjects showed a tendency to perform better on non-skill related measurements while the skilled subjects tended to perform better on skill-specific measurements.

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# CHAPTER I

## INTRODUCTION

The dynamics of contracting muscle is of utmost significance to the training of muscle systems for athletic competition. Much of what is known about muscle dynamics has been revealed through study of the relationship between force and velocity. It has been well documented (28,34,47,51,52,72) that as the force of contraction of a muscle increases the velocity of contraction decreases, concomitantly. Conversely, it is also true that as the velocity of contraction increases the force of contraction decreases.

The original hypothesis explaining the relationship between force and velocity was put forth by Hill (51) who suggested that the diminution in force output as velocity increased was a result of the viscous resistance of the muscle to a change in form. This explanation was never completely accepted by Fenn (28) whose studies showed that viscous resistance was only a small part of the explanation of the force-velocity relationship. Poiseuilles law (92) of the dynamics of fluid flowing through tubes offers much credence to Fenn's argument that viscosity alone is only a small factor in resistance to flow. It has been shown that "when whole blood is perfused through the vascular system of an animal's extremity, no flow is produced until the pressure gradient from arteries to veins reaches 10 mm Hg"(98). This situation is a reflection of the need to overcome the compliance of the vessel walls before enough pressure can be obtained to cause flow. If compliance is a factor in blood flow it can be well imagined that the compliance of a muscle would be many times greater and would prove to be more of a factor in force diminution than viscosity. In further studies Hill (53)

came to realize that resistance due to viscosity was not the answer to the force-velocity question.

From a biochemical viewpoint a feasible explanation of the force-velocity relationship is found by considering the events occurring at the intercepts of the force-velocity curve. At maximal isometric tension ($P_o$), where velocity equals zero, the attainment of peak force is related to the absolute amount of $Ca^{++}$ that can be supplied to the muscle fibers. At the other intercept of the force-velocity curve, which is maximal velocity ($V_{max}$) where $P_o$ is theoretically zero, there is a direct dependence upon the rate at which myosin ATPase can provide energy for contraction by the splitting of ATP. The points along the force-velocity curve are represented by dP/dt which is the rate at which force can be attained and is dependent upon the rate at which $Ca^{++}$ can be supplied as well as the rate at which ATP can be split (66).

This same type of rationale is evidenced in a mechanistic physiological explanation of the events of muscle contraction pertaining to the force-velocity curve. The number of cross-bridges simultaneously in contact per length of sarcomere is important in determining the force output of the exercise at $P_o$. The rate at which the processes of "attaching and detaching" of cross-bridges to actin proceeds is important in determining $V_{max}$. The situation thus evolves that at the ends of the continuum of the force-velocity relationship there exists two situations which are diametrically opposed. At $P_o$ where velocity is zero maximum contact between myosin cross-bridges and actin filament is required while at $V_{max}$ (as Huxley (59) states) if the load is truly zero, then $V_{max}$ should be independent of the number of force generating sites. The cross-bridge reasoning explains the force-velocity relationship in

that $P_o$ and $V_{max}$ cannot occur simultaneously because it is not possible to have maximal cross-bridge contact and minimal cross-bridge contact simultaneously.

With the physiological and biochemical reasoning of the force-velocity relationship considered it becomes understandable why maximal mechanical power output (MMPO) occurs at 30 to 60% of $P_o$ and $V_{max}$ (53,61,95,111).

Many situations in athletics demand a high level of impulse power for the athlete to be successful. Variations in the ability of individuals to manifest impulse power are well documented (69,70,71). Thus, continued investigation of training of muscle systems for athletic competition is of tantamount interest to the coach and the sport science researcher.

## The Problem

Current research has shown that to develop power within a muscle system optimal resistance through the range of motion and optimal speed of contraction must be employed (18,48,117). Through this method primarily fast twitch (FT) muscle fibers are recruited and trained (109). Following upon this concept the purpose of this investigation is to determine the effect of varying the exercise resistance on the development of power in the knee extensor/hip flexor muscle group.

Weight training involving high levels of stress, from a medico-biological viewpoint, can cause tissue damage within the muscles involved (26,113). In order to cope with the sequellae of high resistance exercise a period of reduced resistance exercise should be instituted between high resistance exercise bouts to allow the restitution and "super-restitution" (113) of the muscle tissue through the process of

protein synthesis. Therefore, a sub-purpose of this investigation is to determine the effect of varying exercise resistance on the process of restitution through protein synthesis as indicated by the differentiation in measurable performance variables.

A second sub-purpose is to determine the effect of varying exercise resistance on the development of power in the knee extensor/hip flexor muscle in skilled versus unskilled subjects. Skilled and unskilled are defined under definitions.

## Delimitations of the Study

The study involved twenty-eight healthy, active males. The age range is 18 to 24 years. The study is delimited to the use of non-invasive techniques.

## Limitations of the Study

- The study is limited to the use of isotonic resisted exercise during the training program.
- The study is limited to the physiological analysis of force, velocity and power.
- The study is limited by the use of a power rack which was built at a lifting angle of 53 degrees with the horizontal.

## Assumptions

It was assumed that the distance used for calculation of work was constant through the entire study.

## Definitions

$P_o$ - Force exerted in a maximal voluntary isometric contraction

$V_{max}$ - Maximal velocity of muscle contraction under conditions of zero load

URG - Uniform resistance group. A group that exercised with a

uniform resistance during any one week of the training program.

| | | |
|---|---|---|
| VRG | - | Varying resistance group. A group that exercised with a varying resistance the sequence of which was heavy, light, medium, light, heavy during any one week of the training program. |
| Control | - | A group that performed no resistance exercise during the training program. |
| FT fiber | - | Fast twitch muscle fiber otherwise known as white fiber, phasic fiber, pale fiber, FG (fast glycolytic) fiber |
| ST fiber | - | Slow twitch muscle fiber otherwise known as red fiber, tonic fiber, dark fiber, FOG (fast oxidative glycolytic) fiber, SO (slow oxidative) fiber. |
| Skilled | - | A subject actively involved in a sport requiring vertical jump as a part of the game skill. |
| Unskilled | - | A subject not actively involved in a sport requiring vertical jump as a part of the game skill. |
| Exercise | - | The resisted activity required of the subjects during the training program. |
| Work | - | Force X distance |
| Power | - | Work per unit of time |
| LBM | - | Lean body mass. A subject's total body mass minus total amount of body fat as estimated by the underwater weighing technique. |
| Lift | - | A lift is one movement from start position to complete extension. |
| Repetition | - | A repetition includes all movements from start position to complete extension back to start. |

# CHAPTER II

## REVIEW OF LITERATURE

The review of literature was divided into two parts: (1) the force-velocity relationship; and (2) protein synthesis. The section on protein synthesis was sub-divided into two parts: (2.1) general; and (2.2) exercise induced protein synthesis.

### (1) The Force-Velocity Relationship

The problem of measuring the maximum work done in a muscular contraction inspired Hill (50) in 1920 to develop equipment specifically to this purpose. Hill's apparatus consisted of a lever arm balanced on knife edges with two movable masses provided for balance. The rate of contraction of the muscle could be controlled by adjustment of either the position of attachment of the muscle or by rearrangement of the two movable balanced masses. The same system was used by Doi (25) in 1921 at which time a full description of the apparatus was provided.

In 1922 Hill (51) tendered his "viscous-elastic theory" which was to shape the form of research for the next 16 years until Hill (53) began to question his own theory of viscosity in light of data obtained from his heat of muscle contraction experiments. The viscous elastic theory was the result of experimentation involving measurement of the work done in overcoming the inertia of a heavy flywheel. The flywheel was constructed in such a way that there was a series of progressively larger diameter pulleys around which a string could be attached. When the subject applied a force to the string rotation of the flywheel was produced the velocity of which was measured with a hand tachometer. Alteration of the equivalent mass of the pulley could be accomplished by moving the string to a different diameter pulley. The results indicated

that the greater the equivalent mass moved or the longer the duration of the muscle shortening the greater was the work done. From these results Hill theorized that when a muscle contracts, potential energy is produced. Part is used in doing the external work and part used by the muscle to overcome viscous resistance to change of form. The energy used to overcome viscous resistance was proportional to the speed of contraction and to the coefficient of viscosity of muscle fluids.

Later in the same year Lupton (79) repeated Hill's viscous resistance experiment with some modifications of the method. A quick release pin was added to the flywheel system so that full force could be generated before the flywheel was allowed to move. The method of progression of pulleys was outlined so that the subject started at the largest diameter pulley and proceeded consecutively to the smallest diameter pulley. When the smallest diameter pulley had been employed the order was reversed back to the large diameter pulley again. The results from Lupton's experiment were in agreement with the previous findings of Hill.

Hansen and Lindhard (45) in 1923 used the heavy flywheel concept initiated by Hill with some alterations. A dynamometer was inserted between the handle of the string and the pulley. The length of time for muscle contraction was measured with a stop watch rather than the previously used hand tachometer. The methods were altered by employing two series of measurements per day; the first series started with the largest pulley and progressed to the smallest; the second series proceeded in the reverse order. Also the length of the string was successively varied as the subject placed his arm on the table and made a series of pulls against the dynamometer. This provided for variation of

the angle of flexion at the elbow and allowed the angle of maximal muscle tension for each pulley diameter to be determined graphically. The results indicated in part that the greater the equivalent mass the greater the work done which is in agreement with Hill's findings.

In 1924 Gasser and Hill (34) using excised sartorius muscle of the frog and the lever arm balance system previously devised by Hill and Doi attempted to show the relationship between the shortening speed of a muscle and the amount of external work performed. The muscle was stimulated into a maximal isometric contraction before being allowed to shorten and then was allowed to contract over a fixed distance. The results showed that as the speed of shortening increased the amount of externally performed work decreased, the relationship appeared to be non-linear.

Hill, Long and Lupton (52) in 1926 following the previous research on speed of shortening and external work once again employed the heavy flywheel to verify the previous results in vivo. Using one pulley of the heavy flywheel and the quick release mechanism designed by Lupton the subject made a series of maximal contractions. The quick release pin was pulled from 0 to 3 seconds after initiation of a maximal voluntary contraction. The arbitration time interval was measured with a stop watch. They arrived at the same result as Gasser and Hill in 1924 except that the relationship of speed of shortening to amount of work was linear.

In 1927 Levin and Wyman (72) performed an in vitro study of speed of shortening versus amount of work using the jaw muscles of a dogfish. The methods involved the quick release technique which resulted in an S-shaped curve. They hypothesized that the non-linearity was the result

of the undamped elasticity within the muscle.

Also in 1927 Furusawa, Hill and Parkinson (33) performed further studies investigating the viscous resistance of muscle in vivo. Their research involving measurements from a runner showed that the motion beginning from rest and exerting a maximal effort propelled the runner with a constant force which was retarded by viscous resistance. The equation derived showed that the viscous resistance was proportional to the speed of movement.

Hartree and Hill (47) in 1928 repeating the same experiment as Levin and Wyman in 1927 found that little work was done at the extreme ranges of speed. This seemed to confirm what Hill had found in 1922 that as the speed of contraction increased the viscous resistance of the muscle increased and this, they hypothesized, resulted in little work being done.

In 1928, pursuant to the equation of motion of a runner as derived by Furusawa, Hill and Parkinson in the previous year, Best and Partridge (9) studied the maximal force and viscous resistance of muscles and their effect upon maximum speed of the runner. The research involved one runner who was highly consistant in reproducing his maximal running speed in many trials over one day. The format involved measurement of maximal speed with no external resistance then two or three trials in which the amount of external resistance was varied and finally a trial with no external resistance. The observed results for maximum speed were compared to those predicted from the equation of a runner. The average difference between the two measures was 0.015 yards per second. They derived that the differences between maximal speeds caused by variable external resistances could be calculated from the equation of

motion of a runner. This, they deduced, proved the existence of viscous resistance of a muscle since it had the same effect as an external resistance.

Muscle viscosity and sprint running was the subject of a study by Fenn (28) in 1930. He was concerned that there were some other factors involved in determination of maximal sprint speed which had been grouped under the general heading of viscous resistance. To demonstrate his theory he measured the angular acceleration of the leg of a sprint runner using the quick release method and showed how suddenly the force decreased. The reasons postulated for the sudden decrease in force were: (1) reflex inhibition of the muscle; (2) an intrinsic characteristic of the muscle; and (3) a necessary chemical reaction delaying mobilization of energy needed for muscle contraction. Under these circumstances he stated "the term viscosity would be inappropriate".

The following year Fenn in conjunction with Brody and Petrilli (20) again examined the loss of force during rapid shortening using the quick release method after isometric contraction. To accomplish this they first obtained kymograph records of limb velocities after quick release as a function of time and from the angular velocities they graphically calculated the angular acceleration. Knowing the moment of inertia for the limb they calculated the forces acting at various moments through the motion. By measuring the isometric force exerted and then pulling the pin and recording the resultant angular acceleration the moment of inertia of the limb was calculated. The two calculations (moment of inertia and force at various moments) were found to agree within 10%. The force exerted in the quick release experiment was plotted against velocities at various stages of limb swing which indicated

that force decreased as speed of movement increased.

Stevens and Snodgrass (104) in 1933 measured speed of shortening, force, amount of work done and power expended for every 0.011 second of shortening of the gastrocnemius muscle of a decerebrate cat. The format of their experiment was such that length and tension were both allowed to vary during the same contraction working against inertia. In this way a relationship between length and tension during the same contraction was derived. The results of the experiment indicated from a force-velocity graph that after maximal tension had been developed contraction velocity increased as force generation decreased. The diminution of force was hypothesized to be caused by the viscous resistance of the muscle. They also noted that even though force generation and speed of shortening were related inversely this was based upon the fact that power generation was constant.

In 1934 Stevens teamed with Metcalf (105) and repeated the identical study that he had been involved in the previous year with the result being the same. As speed of contraction increased force decreased in a linear relation. They again reasoned that this result was due to the viscous resistance of the muscle to change of form.

Fenn and Marsh (30) in 1935 did an in vitro study on mainly sartorius muscle of the frog to determine the relationship between force exerted and speed of muscle shortening. The velocities measured were at the start of contraction where slope was maximal and constant. Since the velocities measured were always constant the assumption was made that the force output of the muscle would be equal to the load lifted. Force output was made a relative measure by expressing it as force per square centimeter of muscle in cross section. The format of the experi-

ment involved stimulating the muscle to contract under various loads from a minimal load to a maximal load and then reversing the order. The maximum velocity of contraction was measured for each repetition and always at the same length. The results indicated a force-velocity relation which was not linear but rather an exponential curve. From this the researchers hypothesized that there were other factors affecting the force-velocity relationship than viscous resistance of the muscle. It was concluded that the curved relationship was in some way reflective of a process of extra energy development for work of muscle shortening.

In 1938 A. V. Hill (53) performed what were probably the most significant experiments in muscle physiology to that date. The basis for the change in approach was that Hill developed a thermopile technique for measuring heat liberated during contraction of a muscle. In this way he once again investigated the force-velocity relationship by recording the amount of heat liberated during a contraction under various loads. The quick release method was employed after an isometric contraction. The results of the experiment indicated that as a muscle shortened extra heat was produced. Further investigation showed that the relationship between load and heat (energy) liberation was a linear function, i.e. as load increases heat liberation decreases until at maximal isometric tension the heat of shortening is zero. From the findings Hill was able to derive his famous "characteristic equation of a muscle" which related the rate of heat produced to the load.

The equation derived was:

$$(P + a)v = b(P_o - P)$$

where:

$P$ = load on the muscle;

$a$ = constant with dimensions of force;

$v$ = velocity of shortening;

$b$ = constant defining the absolute rate of energy liberation; and

$P_o$ = maximal isometric force

The equation in an alternate form which related speed of shortening and force was:

$$(P + a)(v + b) = (P_o + a)b = \text{constant}$$

where:

$P$ = load on the muscle;

$a$ = constant with the dimension of force;

$v$ = velocity of contraction ;

$b$ = constant with the dimension of velocity; and

$P_o$ = maximal isometric force

Continuing on with another set of experiments under the same project heading Hill examined the effect of eccentric contractions upon heat production. By applying greater loads than what the muscle could support at maximal isometric tension the muscle became forcefully elongated with a resultant negative change in heat production. The energy production in an eccentric contraction was less than that found for an isometric contraction. This finding was the catalyst for the rejection of the viscous resistance model as an explanation of the force-velocity relationship. Hill reasoned that if viscous resistance were the reason for the decrease in force as speed of shortening increased, and heat production varied linearly with force, then when the shape of the muscle

was forcibly changed under negative loading one would once again expect the overcoming of viscous resistance to cause an increase in heat production and certainly not a negative change. Therefore he concluded that viscous resistance was not a primary factor in the force-velocity relationship which was what had been stated by Fenn (28) in 1930.

Concomitant to the realization of the role of viscous resistance in muscle contraction Hill also noted that the peak rate of performing work (power) should be found in the range of 30% of maximal voluntary contraction force.

In 1939 Katz (67) replicated the work done in the previous year by Hill. The object of his experimentation was to confirm the validity of Hill's characteristic equation. To accomplish this Katz used the sartorious muscle of various strains of frogs and also used the retractor penis of the tortoise. His methodology involved using the constants of a and b from the characteristic equation to predict the relation of the force-velocity curve. The data that was collected from the various muscle samples fit very closely the predicted force-velocity curve.

Ralston, Polissar, Inman, Close and Feinstein (95) in 1949 used a group of amputee patients having cineplastic muscle tunnels to study the contractions of various upper limb muscles under isometric and isotonic conditions. The isometric contractions were measured by a strain guage dynamometer. The contraction velocity was determined by incorporating a bridge mechanism into the cable attached to the resistance load. Deflection in the bridge upon contraction of the muscle was measured electronically and provided a time course for the muscle contraction. The method used was a replication of Fenn and Marsh's (30) 1935 study and Hill's (53) 1938 study on frog muscle. The muscle was

prepared for contraction by pre-stretching with a light load to a position just beyond resting length. Upon a signal the subject contracted the muscle as quickly as possible. The sequence of loading was from minimal load to maximal load and reverse. The results were found to very closely resemble those predicted from Hill's characteristic equation using excised frog muscle. The range for peak power output, they concluded, was from 25% to 40% of maximal isometric tension.

Wilkie (114) in 1950 used a triangular oak lever axle which ran freely in self-centering ball bearings to determine the relation between force and velocity in human arm movement. The subjects pulled on a lever through a Bowden wire cable in which the tension was varied by altering a suspended weight. The subject kept his upper arm fixed during each movement by pressing it against a padded block of wood fastened to the table. In order that the force applied by the arm be constant throughout each movement, the cable remained horizontal. The velocity of each movement was estimated from a charge which accumulated on a condenser. The velocity of the subject's hand was always measured at the end of the movement, when the arm was at an angle of $80^{\circ}$ with the horizontal. The load was supported by a stop so that the lever was at $140^{\circ}$ with the horizontal before each movement. At the end of the movement ($75^{\circ}$) the load was held by a spring catch. The isometric tension was measured by a simple spring balance, with the forearm at an angle of $80^{\circ}$ with the horizontal, that is, in the same position at which velocity was measured. For one subject, the tension at the hand was varied in eleven steps from 0 to 15.23 kilograms and at each step 30 measurements of velocity were made. Only five velocity measurements at the same tension were made at one time and each one followed a rest period of at least one minute to

avoid fatique. An attempt was made to fit the exponential curve of the resulting measurements to the force-velocity curved predicted by Hill's characteristic equation. It was found that the two curves were only in agreement at forces above 30% of maximal isometric tension. It was reasoned that the fit of the curves was being affected by the inertia of the apparatus and the forearm. When these factors were partialed out the curves seem to fit each other very well. Data collected from an additional 4 subjects on whom 5 points for plotting the force-velocity curve were used instead of 30 were found to fit the curve of the characteristic equation when the inertia of apparatus and forearm were accounted for.

Abbot and Wilkie (1) in 1953 were interested in assessing the force-velocity relationship when it was initiated by quick-release from lengths other than resting. This investigation was a resultant of the fact that Hill had measured $P_o$ at resting length and in his characteristic equation $P_o$ appears as a constant. The format for the experiment involved using the sartorius muscle of frogs to determine tension-length curves both before and after a series of isotonic contractions. Their results indicated that Hill's characteristic equation applied as long as $P_o$ was determined for the initial length of the muscle before contraction.

MacPherson (80) in 1953 wanted to investigate the effect of compliance of the muscle's attachment to determine its effect on the force-velocity curve. In his experiment he compared two isometric contractions, one with and the other without a known compliance added in series, in order to calculate the force-velocity relation of the frog sartorius muscle. The sole assumption required was that the velocity of shorten-

ing at any moment was a function only of the load at that moment. The tension developed by the muscle and the rate of change of tension were recorded simultaneously throughout the growth of a maintained isometric contraction. A similar record was made with extra compliance. The results revealed that the force-velocity curve always emerged with the expected form.

Ritchie and Wilkie (96) in 1958 used the sartorius muscle of the frog to determine force-velocity curves from isotonic contractions. They found that about one-third of the force-velocity curves from the experiments did not fit when Hill's equation was applied because they had a straight region at the high force-low velocity end. They found a better agreement between experimental results and the predicted curve by using Carlson's equation which was not tied down to any specific algebraic formula for the force-velocity curve. Carlson's equation for the motion of a tetanized muscle is:

$$P = F_1(X) + F_2 \frac{dx}{dt} \quad ,$$

Where $F_1(X)$ and $F_2(dx/dt)$ are empirical functions describing the shapes of the tension-length and force-velocity curves respectively.

Hill (55) in 1964 used the frog sartorius muscles to show the efficiency of mechanical power developed and its relation to load. In most of the experiments the muscles were allowed to shorten as soon as they could lift the load. In a few experiments, they were released later. Hill found that the optimum load for efficiency was about 45% full isometric tension. The optimum value for power development was practically constant at about 30% of maximal isometric force.

Chui (15) in 1964 investigated the comparative effects of isometric and dynamic weight-training exercises on strength and on speed of execution of single movements. Seventy-two males were divided into four groups: Group I (isometric contraction method); Group R (rapid dynamic contraction method); Group S (slow dynamic contraction method); and a control group. A cable tensiometer was used to obtain eight strength scores for each subject. Speed of movement times against no resistance in six movements and against resistance in the same movements in specified increments were taken. All of the training groups gained in strength and at the same time gained in speed of movement measured against no resistance and against resistance. He concluded that gains in strength exerted in performing a movement are accompanied by gains in the speed of execution of the same movement against no resistance and against resistance. It was a further conclusion that gains in strength and gains in speed of movement against no resistance and against resistance made by the use of the one method are not significantly greater ($P = .05$) than gains made by the use of the other method.

Ikai (61) in 1970 was the first to apply the knowledge gained from the study of the force-velocity relationship to training individuals in power development. He determined force-velocity curves for males and females and found that maximum power was produced at approximately 35% of maximal force and maximal velocity in both sexes. Armed with this information he conducted a power training study on the forearm flexors of twelve males to determine what the effect would be on the force-velocity curve. The training groups exercised at zero, thirty, sixty or one-hundred percent of maximal isometric tension ($P_o$). The training

involved completing ten maximal voluntary contractions of the elbow flexors once a day at the pre-determined load. The results indicated that the best over-all power training program, which provided the greatest displacement of the force-velocity curve, was found for the thirty and sixty per cent of $P_o$ training groups.

Moffroid and Whipple (84) in 1970 performed a study to evaluate the effects of two different training speeds on muscular endurance and on muscular force. The format of the study was to administer a pretest, a specific training program, and a post-test. Two experimental exercise groups (one exercising at a low power output, and the other at a high power output) were compared with each other in terms of torque increases and endurance increases. The control group constituted a third group and received no exercise. The study concluded that exercise is speed specific in the following ways:

1. Low power (low speed, high load) exercise produces greater increases in muscular force only at slow speeds.
2. High power (high speed, low load) exercise produces increases in muscular force at all speeds of contraction at and below training speed.
3. High power exercise increases muscular endurance at high speeds more than does low power exercise increase muscular endurance at low speeds.

At the IIIrd International Seminar on Biomechanics in 1971 Komi (75) presented a paper in which he outlined the design of a dynamometer for measuring the force-velocity relationship of the human forearm flexors and extensors. The dynamometer was capable of recording both the isotonic force (either eccentric or concentric) and changes in muscle

length (elbow angle) with eight different velocities of shortening and lengthening of the elbow flexors and extensors. Thus, to obtain the force-velocity relationship, a total of sixteen different constant speeds could be selected along the velocity axis. The dynamometer was isokinetic by design for both eccentric and concentric contractions of the biceps brachii throughout the movement range of approximately $120^{o}$. This degree of flexion corresponds to a seven centimeter change in the length of the biceps muscle of an adult male. The speed range varied from 0.8 to 6.7 centimeters per second when measured from the biceps muscle. The velocity of contraction was obtained with a photo-electric transducer which gave an impulse on an oscillograph at each spindle revolution. Strain gauges to record the force were installed on both sides of a special wrist cuff, which allowed the wrist to be fixed at any desired position between full supination and full pronation. The force-velocity curves that were obtained for the elbow flexor muscles followed closely the classical force-velocity form obtained with isolated muscle.

Kawahatsu and Ikai (60) in 1971 devised a system of pulleys and weights to isotonically resist the knee extensor muscles. To the pulley was attached an electrogoniometer which allowed the determination of angular velocities. The exerted force was measured by a strain gauge tensiometer. In this way it was possible to calculate maximal mechanical power output. Using this equipment Kawahatsu found a variation in the relative displacement of the force-velocity curve which was specific to an athletic event. The force-velocity curve recorded for sprinters was the highest followed by middle distance runners and long distance runners who had the lowest curve.

In the following year Kawahatsu and Ikai (70) used the identical apparatus to compare the force-velocity curves of children, adults and athletes. They found that the maximum velocity of movement differed between a five year old child and a male adult by 75.5% and increased as the exerted forces increased. They also found that a high jumper and a sprinter were equal on peak maximal mechanical power output but the jumper used a greater ratio of force against his maximum isometric force than did the sprinter. However, the sprinter produced an equal peak power by providing a higher ratio of velocity against the maximum velocity.

In 1974 Kawahatsu (71) turned his attentions to studying the variation in power output with increasing age. In this study he tested 277 males in the age range of 15 to 72 years. All measurements were taken on the knee extensor muscles of the right leg. The results showed a significant difference in force, velocity and power between age groups. Also he found that the maximal isometric force ($P_o$) decreased considerably after the age of 20 years while the maximum unloaded velocity as well as maximum exerted force decreased after 15 years of age.

In the same year Kawahatsu (72) performed a longitudinal study using continuous training on the bicycle ergometer to improve maximal mechanical power output. He found the greatest displacement of the force-velocity curve occurred at peak maximal mechanical power output. He concluded that the increase was due mainly to an increase in force output at that point with little increase in maximal velocity of contraction. He also found that there was no significant difference in maximal isometric tension ($P_o$).

Thorstensson, Grimby and Karlsson (109) in 1976 took measurements of the force-velocity relationship of the knee extensor muscles in 25 male subjects (17 - 37 years) by means of isokinetic contractions. Muscle biopsy specimens were obtained from the medial portion of vastus lateralis muscle and classified as fast twitch (FT) and slow twitch (ST) fibers on the basis of myofibrillar ATPase actively. The fiber area was measured on the basis of NADH diaphorase staining. The investigators found that dark staining fibers (FT) have a higher myosin ATPase activity, and that myosin ATPase activity in turn is inversely related to muscle contraction time. They also found motor units demonstrating higher tension outputs and shorter contraction times contain fibers that could be classified as FT with the present histochemical technique. They concluded from the results that it is reasonable to suggest that a high percentage of FT muscle fibers is one prerequisite for performing fast contractions with appreciable tension outputs.

In 1975 Osternig (88) tested the torque values of the quadriceps muscles of 16 college football players by means of an isokinetic dynamometer in order to determine the optimal loads and velocities producing muscular power. The subjects were tested at velocities ranging from 5 to 25 rpm and through a range of knee extension between the positions of $80^{\circ}$ to $50^{\circ}$ of knee flexion. Isometric measures were also recorded at corresponding angles. The muscular torque values recorded isokinetically at the various velocities were then compared to the isometric forces at the corresponding angles of knee extension to ascertain the arithmetic proportion of isokinetic to isometric torque which produced maximum muscular power. The results indicated that the proportionate values of isokinetic to isometric torque and isokinetic velocities which produced

maximum power were not directly comparable to similar loads and velocities found in vitro.

Thorstensson, Larsson, Tesch and Karlsson (110) in 1977 studied international calibre Swedish athletes and a group of sedentary men to determine the relationship between muscle fiber characteristics in needle biopsy samples from vastus lateralis and muscle strength measured as peak torque during isokinetic knee extensions. In comparison with the sedentary group the following differences were found: a) percentage fast twitch fibers was lower in the endurance athletes; b) fast to slow twitch muscle fiber area ratio was higher in the track athletes; c) track athletes and downhill skiers attained higher peak torque values at all angular velocities examined. The track athlete had, however, higher torque values at the fastest angular velocity as compared to the downhill skiers, whereas there was no difference under isometric conditions. The proportion of fast twitch fibers was related to torque produced, especially at high motion velocity. The training also appeared to affect the force-velocity relationship.

Jones (65) in 1977 studied the effect of isokinetic training on the force-velocity relationship and the development of maximal mechanical power output in the forearm flexors of 42 women. The subjects were divided into 6 groups based upon their maximum force generated at peak power. Experimental groups were classified into 2 high and 2 low force groups while 2 groups acted as control. The high and low training groups were each assigned to a differential 5 week isokinetic training program of 30 and 60% maximum isometric force ($P_o$). The conclusions of the study were that the 60% of $P_o$ training stimulus is more effective in displacing the force-velocity curve "all around" regardless of the

high or low classification. At high velocity power output the 30% of $P_o$ training is more effective. General increases in power are best obtained by a differential training stimulus (30 and 60% respectively).

Perrine and Edgerton (93) in 1978 studied muscle force-velocity and power-velocity relationships under isokinetic loading. The study involved 15 males and females, 18 to 38 years old and from various activity patterns from sedentary to athletic performing maximal dynamic knee extensions on an isokinetic dynamometer. Maximal torque forces attained at 30$^o$ before full extension and at seven loading velocities from 0 to 288$^o$/second were recorded. The maximal 30$^o$ torques exhibited by the various subjects ranged from 29 to 245 Newton-meters. Maximal instantaneous power output at the 30$^o$ position ranged from 98 to 680 Watts. In all subjects this was attained at and generally remained constant over the three highest test velocities (192 to 288$^o$/sec). A neural mechanism that restricts a muscle's maximal tension in-vivo is postulated as being responsible for the marked difference between the force-velocity relationship found for human muscles in-vivo and that exhibited by isolated animal muscles.

Lesmes, Costill, Coyle and Fink (76) in 1978 investigated the effects of short duration, high intensity training on skeletal muscle. The extensors and flexors of the knee were tested and exercised by means of an isokinetic dynamometer. Measurements of peak torque were obtained at velocities ranging from 0$^o$/sec to 300$^o$/sec through a distance of 90$^o$. Total work output was measured during repeated knee extensions and flexions for work tasks of 6 sec and 30 sec duration. A one minute test of repeated maximal contractions was administered to examine muscular fatiguability before and after training. The subjects trained one leg

with repeated 6 sec exercise bouts, while the other leg was trained using 30 sec bouts. All training and testing was executed at near maximal force and at a constant velocity (180°/sec). The subjects trained four times per week for a period of seven weeks. The daily work output was equal for the 6 and 30 sec training legs. Results indicated that: 1) isokinetic training programs of 6 and 30 seconds duration can increase peak muscular torque; 2) training velocity may be an important consideration in improving peak torque; 3) total work output was increased an average of 30% with either training at relatively slow (60°/sec) or fast (180°/sec) velocities; 4) both training programs significantly reduced the fatiguability of the knee extensor muscles.

(2) Protein Synthesis

(2.1) General

In 1969 Short (102) studied the rate of incorporation of $^{14}$C-methionine into protein of red and white muscle fibers during incubation in-vitro. Rats were divided into two groups by age. Red and white fibers were teased from hindleg adductor muscles and half of the fibers were incubated in the presence of insulin. Short found that methionine incorporation into protein was more rapid in red than in white muscle and was stimulated by insulin in both fiber types. The muscle of younger rats exhibited more rapid methionine incorporation than that of older rats. It was concluded that the difference in rate of protein synthesis between red and white muscle is not wholly dependent on intact innervation or blood supply, and that the stimulatory effect of insulin on muscle protein synthesis occurs in both fiber types.

Buresova, Gutmann and Klicpara (12) in 1969 performed experiments on levator ani and extensor digitorum longus muscles of a rat to determine the effect of tension upon rate of incorporation of amino acids

into proteins. Results show that incorporation of $^{14}C$-leucine into proteins in stretched muscles is considerably higher than into the proteins of muscles freely incubated. Expressed as a percentage difference levator ani increased by 174% and extensor digitorum longus increased by 50%. The authors postulated the mechanism for increase may be linked to increase in oxygen consumption of stretched muscle. Also, the effect may be due to the fact that unstretched muscle coils and may go into contracture thus reducing the surface area of the muscle to incubation. It was concluded that the use of stretched muscle in incorporation studies offers advantages and maintains more natural conditions for muscle function.

In 1970 Millward (83) performed a study into the feasibility of using $^{14}C$ $Na_2CO_3$ to label skeletal muscle protein because of its purported low reutilization rate. The format involved using three labels to determine turnover rate of rat skeletal muscle. The three labels were $^{75}Se$ seleno-methionine, 6-$^{14}C$ arginine and $^{14}C$ $Na_2CO_3$. The half-life of the first two labels was quite lengthy in comparison to $^{14}C$ $Na_2CO_3$. Following the injection of $^{14}C$ $Na_2CO_3$ muscle protein was maximally labelled after 6 hours, at which time the specific activity of the free amino acids had fallen to a very low level. Aspartate and glutamate in particular had lost over 99% of their maximum activity in comparison to arginine which was still highly labelled after 24 hours. It is postulated that aspartate and glutamate labelled by the injection of $^{14}C$ $Na_2CO_3$ are only reutilized to a very small extent and therefore afford the means by which the rates of protein synthesis and catabolism in skeletal muscle can be measured with reasonable accuracy.

Pain and Manchester (91) in 1970 studied the influence of electrical stimulation in-vitro on protein synthesis in rat extensor digitorum longus muscle. From their investigation they concluded that it seemed unlikely that protein synthesis would be enhanced during exercise in-vivo, but rather the reverse, and the increase in protein formation after exercise is more probably a compensatory response to an initial decline than a result of the exercise per se.

Goldberg (38) in 1972 investigated tonic and phasic muscle to determine if the level of protein synthesis in different skeletal muscles varies systematically with different types of physiological activity. The protocol for the experiment involved injecting $^{14}C$-leucine subcutaneously 24 hours previous to sacrificing the animals at which time 50 mg samples of each muscle were taken for analysis. The proteins in each fraction were isolated and their radioactivities were assayed. The dark muscles incorporated more $^{14}C$-leucine into both soluble and fibrillar proteins than did the pale ones. It was hypothesized that the different rates of protein degradation could arise in 2 ways: 1) certain proteins found only in red muscles could be very short lived and therefore the amount of protein catabolized at any time would appear greater; 2) the same proteins may turn over at different rates in the different muscles, being more labile when the muscles are used tonically than phasically.

Funabiki (32) in 1972 investigated the turnover of myofibrillar protein. The conclusion of his study was that not only the myofibrillar components but also the thin filament components, actin, tropomyosin, and troponin, have different rates of turnover and do not degrade as a unit.

Jefferson, Rannels, Munger and Morgan (64) in 1974 investigated the effect of insulin in the regulation of protein turnover in heart and skeletal muscle. The investigators stated that the pathway of protein synthesis has been considered to consist of: 1) transport of amino acids into the cell; 2) activation of amino acids to form aminoacyl - tRNA's; and 3) polymerization of intracellular amino acids into protein. They concluded that the addition of insulin reduced the rate of protein degradation by approximately 50% in heart and 70% in skeletal muscle.

Lundholm and Schersten (78) in 1975 studied the incorporation of leucine into human skeletal muscle proteins. Their findings indicated that amino acids proteolytically released intracellularly can return to be once again available for incorporation by reassociation at the "transport" membrane and that these amino acids have a competitive advantage for incorporation as compared with free intracellular amino acids. They further postulated that if this is true, in-vitro determinations of protein synthesis will necessarily give falsely low values independent of which amino acid pool is used for the calculations of the synthesis rate. However, by using a high concentration of amino acids in the medium this error seems to be low.

Flaim, Li and Jefferson (31) in 1978 looked at the effects of hypophysectomy and growth hormone upon protein turnover in rat skeletal muscle. They postulated that growth hormone appears to act on protein turnover at several levels. In hypophysectomized rats, protein synthesis is affected dramatically by decreased RNA levels, and the concomitant decrease in protein degradative rates are such that no growth occurs. With growth hormone treatment, the effect on protein synthetic efficiency alone would lead to an estimated muscle growth rate of 1% per day. This

effect coupled with a lack of increase in protein degradative rate and undetermined but probably similar shifts in other tissues must account for a recorded whole-body growth rate of 2.3% per day.

(2.2) Exercise Induced Protein Synthesis

Goldberg (35) in 1967 initiated a study to determine whether work-induced growth of muscle requires pituitary growth factors. Compensatory hypertrophy was induced in the rat soleus and plantaris muscles on one limb by cutting the tendons of the synergistic muscle, the gastrocnemius. The contralateral limb received only a sham operation and served as a control. Within a week, the wet weight of the plantaris of the operated limb was 20% greater and that of the soleus 40% greater than their controls. Growth was evident within 24 hours and reached its maximal extent by 5 days. Histological evidence showed that this weight increase was correlated with increased diameters of the muscle cells. The rate and extent of muscle hypertrophy were similar in hypophysectomized and normal animals. Goldberg concluded that pituitary growth hormone is not essential for skeletal muscle hypertrophy and that two types of muscle growth can be distinguished: 1) growth hormone-dependent type; and 2) work-induced hypertrophy.

Kendrick-Jones and Perry (73) in 1967 examined the question of protein synthesis and enzyme response to contractile activity in skeletal muscle. They employed the sartorius muscle of a frog which was made to contract isometrically once every 5 seconds for 6 hours at $18^{o}$ centigrade by supramaximal stimuli from a multi-electrode assembly. They found that the activity of ATPase does not respond so readily to repeated contraction as do CPK and other sarcoplasmic enzymes. They also found that new enzyme had been synthesized as a result of continued contractile

activity. Their conclusion was that protein synthesis is induced by repeated contractile activity as evidenced by incorporation of labelled $^{14}C$-leucine.

Gordon, Kowalski and Fritts (42) in early 1967 investigated the variation in effects of different exercises on the various constituents of muscle. The methodology involved training rats in either prolonged running or swimming. After three months, the concentration of sarcoplasmic protein increased and that of myofibrillar protein decreased in quadriceps, gastrocnemius and soleus muscles. They also found that although gross muscle size generally decreased, muscle fiber size did not invariably parallel this change. One pattern of response was an increase in mean areas of both red and white muscle fibers; in a second pattern, mean area decreased in red fibers and increased in white. They concluded that gross size of muscle is an equivocal criterion of hypertrophy or increased performance; it is fiber size that counts.

Later in the same year Gordon, Kowalski and Fritts (43) examined changes in rat muscle fiber with forceful exercises. Rats were trained in standing and climbing with loads (static and dynamic forceful exercises). They found that these regimens provoked a "myofibrillar protein hypertrophy" that was reflected in an increased concentration in muscle fiber and in increased strength. Muscle weights did not increase, but trained animals showed a higher muscle weight-body weight ratio than that established for a large series of inactive rats of the same strain. They also found on the microscopic level the mean area of white fiber increased; but that of red fiber did not always increase. From this they hypothesized that actomyosin hypertrophy comes from brief, forceful exercises and results in increased strength; sarcoplasmic hypertrophy

stems from prolonged, repetitive exercises and results in enhanced local muscle endurance afforded by increased capacity for energy metabolism.

Goldberg (36) in 1968 studied the incorporation of $^{14}C$-leucine into proteins during compensatory growth of the soleus and plantaris muscles. Growth of these muscles of one limb was induced by tenotomy of the synergistic gastrocnemius muscle. He found that at the end of the growth period, these muscles showed greater incorporation of $^{14}C$-leucine into proteins than did contralateral controls, and the final gain in muscle weight was directly proportional to the increase in amino acid incorporation. Soluble and myofibrillar proteins appeared to be synthesized in the same proportions as in nongrowing muscles. The relative incorporation of $^{14}C$-leucine into various sarcoplasimc components (mitochondria, Ca-binding grana, microsomes, and soluble proteins) was also similar in hypertrophying and control muscles. The increase in amino acid incorporation, however, appears too small to account entirely for the gain in muscle weight.

The following year Goldberg (37) compared the rates of protein catabolism in nongrowing skeletal muscle, in muscle undergoing work-induced hypertrophy and in muscles growing in response to treatment with pituitary growth hormone. Hypophysectomized rats were injected initially with $^{3}H$-leucine, and on subsequent days received unlabeled leucine and a high protein diet to minimize reutilization of the $^{3}H$-leucine. Rates of protein degradation were estimated from the loss of radioactive proteins. Rates of protein synthesis were estimated from the amount of dilution of previously labeled proteins with newly synthesized unlabeled material (decrease in specific activity). Two days after injection of $^{3}H$-leucine, hypertrophy of soleus of one limb was induced by sectioning

the tendon of the gastrocnemius muscle. It was found that during compensatory growth, the soleus retained more of the labeled proteins than its contralateral control muscle. He concluded that during hypertrophy there is decreased protein catabolism as well as increased synthesis of new proteins. In addition, the degradation of sarcoplasmic proteins decreased more markedly than that of myofibrillar proteins, resulting in a relative increase in the sarcoplasmic proteins during compensatory growth.

Terjung, Winder, Baldwin and Halloszy (106) in 1973 studied the effect of exercise on the turnover of cytochrome c in skeletal muscle. This study indicated that the radioactivity of cytochrome c decreased significantly more slowly in quadriceps muscles of rats subjected to a program of running than in muscles of sedentary animals. The half-life of muscle cytochrome c was 32 days in the sedentary animals and 48 days in the runners. The synthesis rate of cytochrome c was calculated to be approximately 0.630 n mole per muscle per day in the sedentary and 0.771 n mole per muscle per day in the exercised animal. They concluded that the increase in the concentration of cytochrome c that occurs in hind limb muscles of rats subjected to programs of running is the result of both an increase in the rate of synthesis and a decrease in the rate of degradation, with the latter playing a considerably more important role.

Bailey and Bell (3) in 1973 evaluated the effects of physical exercise on the growth of skeletal muscle tissue. Male Sprague-Dawley rats 3 weeks of age were divided into exercise and control groups and equal numbers of each group were sacrificed at 3, 6, 9 and 12 weeks of age. The results showed a significant difference ($P < .05$) between exercise and control animals in DNA concentration at 12 weeks of age and in the protein/DNA ratio at 6 weeks of age. It was concluded that exercise

has a positive effect on skeletal muscle DNA concentration and protein content during pre-pubertal growth.

Staudte, Exner and Pette (103) in 1973 studied the effects of short term, high intensity (sprint) training on contractile and metabolic characteristics in soleus and rectus femoris muscles of female rats. In terms of contractile characteristics they found that isometric twitch contraction time decreased in the soleus muscle and maximum tetanic tension increased in soleus and rectus femoris muscles.

Thorstensson, Sjodin and Karlson (107) in 1975 investigated enzyme activities and muscle strength after "sprint training" in man. Sprint type strength training was performed 3 to 4 times per week for 8 weeks by 4 healthy male students (16 - 18 years of age). The training was carried out on a treadmill at high speed and with high inclination. Muscle biopsies were obtained from vastus lateralis muscle before and after the training period for histochemical classification of slow and fast twitch muscle fibers. The findings showed Sargent's jump increased on average by 4 centimeters, maximal voluntary contraction increased by 19 kp, and endurance at 50% of maximal voluntary contraction increased by 9 seconds. Muscle fiber type distribution was unchanged, whereas fiber area indicated an increase for both fiber types in 3 subjects after training.

Jaweed, Gordon, Herbison and Kowalski (63) in 1974 examined protein changes in skeletal muscles as adaptations to endurance and strength exercise. Female Wistar rats, 17 weeks old, were divided into 14 trios, with members of each trio being identical in body weight. One member from the trio was allowed to run, voluntarily, in a nonmotorized running wheel for six weeks for 4 - 6 hours each day. The second animal was

subjected to a weight lifting program in which rats climbed a vertical ascent of 40.6 cm 50 times daily for a period of six weeks. In the final two weeks, the animal carried 200 gm on it's back (in addition to it's body weight of 240 to 280 gm). The third member of the two remained in the cage as inactive control. The results showed rectus femoris, vastus medialis and soleus, which represented the mainly white, red and intermediate fiber types respectively, showed increments in the concentration of sarcoplasmic proteins due to running and in myofibrillar proteins after weight lifting exercise. All three muscles, despite a different fiber type composition, indicated a similar pattern of change in soluble proteins, which augments the hypothesis that the adaptations in skeletal muscle due to endurance and strengthening exercises may be specific to the type of stress.

Hubbard, Smoake, Matthew, Linduska and Bowers (57) in 1974 investigated the effects of growth and endurance training on protein and DNA content of various muscles of the rat. Male Sprague-Dawley rats were assigned to three untrained groups, and two trained groups containing 18 - 34 animals per group. The trained groups were forced to exercise on a motor driven treadmill under a shock avoidance contingency. The animals were exercised thirty minutes per day, five days a week with the treadmill set at a $6^{o}$ incline for up to twelve weeks. The first week, the animals were exercised at a belt speed of 15 meters per minute. Each week the treadmill speed was increased by five meters per minute until the fourth week when the animals were running at 30 meters per minute. This speed was maintained throughout the remainder of the training period. The results showed the average wet weights per nucleus of soleus, plantaris and gastrocnemius muscles increased in rats between

39 and 90 days of age; after which they plateaued. Although each extensor muscle had a different adult value for weight per nucleus, it was higher in mixed muscle. The DNA concentration of the slow twitch soleus muscle was nearly double that of the fast twitch mixed muscles. Although the concentration of muscle DNA on a wet weight basis fell markedly between 39 and 90 days of age, the number of nuclei per muscle nearly tripled. The data suggest that endurance training may slow the rate and prolong the phase of nuclei accumulation. DNA concentration in young muscle appears unrelated to the size of the adult muscle and may indicate neurally mediated differences in the rate of protein synthesis. Endurance training did not selectively stimulate the hypertrophy of muscle sacroplasmic, myofibrillar or stromal protein, but prevented the 3 to 5 fold drop in running time to exhaustion seen in older, sedentary rats.

Hubbard, Ianuzzo, Matthew and Linduska (58) in 1975 studied compensatory adaptations of skeletal muscle composition to a long-term functional overload. Compensatory hypertrophy of rat plantaris muscle was induced by cutting the attachment of the synergistic gastrocnemius muscle. The sham-operated contralateral muscle served as a control. Within 5, 30 and 60 days postoperatively, the wet weight of the hypertrophied plantaris was 40, 60 and 109% greater respectively, than the contralateral control. Two patterns of changing muscle composition emerged with compensatory hypertrophy: 1) an early (less than 5 days) increase in DNA content (+190%) which resulted in a sharp decline in the wet weight per nucleus ratio (-50%). This coincided with an increase in sarcoplasmic and stromal proteins and a fall in myofibrillar protein concentration. These changes were followed by 2) a secondary increase (30 - 60 days post-

operatively in the proportions of myofibrillar proteins with a corresponding decline in sarcoplasmic proteins.

McManus, Lamb, Judis and Scala (81) in 1975 looked at skeletal muscle leucine incorporation and testosterone uptake in exercised guinea pigs. They found that hypertrophy of the plantaris muscle did not occur with chronic exercise even though labeled leucine incorporation was elevated. This, they concluded, implies that increased protein degradation was coupled with the observed enhancement of leucine incorporation and suggests that the muscle protein turnover rate was increased.

Goldberg, Etlinger, Goldspink and Jablecki (39) in 1975 researched mechanisms of work-induced hypertrophy of skeletal muscle. Their purpose was to define more precisely the early events in hypertrophy by studying the contractile activity of rat muscles in-vitro. They found that electrical stimulation enhanced active transport of certain amino acids within an hour, and the magnitude of this effect depended upon the amount of contractile activity. Stimulation or passive stretch of the soleus or diaphragm also retarded protein degradation. In-vivo under the same conditions, or even more prolonged stimulation, no change in rates of protein synthesis was detected. They concluded that increased tension development (either passive or active) is the critical event in initiating compensatory growth.

Booth and Holloszy (10) in 1976 undertook to determine whether the increase in cytochrome c in exercised muscle is due to increased synthesis, decreased degradation, or a combination of the two. In the first section of the study rats were taught to run on a treadmill for 10 minutes per day for 4 weeks. The work was then increased in one step to 100 minutes of running at 1 mile per hour daily, 7 days a week. This

was done because it is essential that the inducing stimulus be kept constant throughout if the half-life of a protein is to be determined. Rats were killed at various time intervals after the start of the 100 minute per day training, and cytochrome c concentration was determined in their muscles. The half-life of the increase in cytochrome c was about 6 days in the soleus and vastus muscles and about 7.5 days in plantaris muscle. In the second section of the study a similar half-life was obtained for the decrease in muscle cytochrome c to baseline levels after the cessation of training. Booth and Holloszy concluded that the increase in cytochrome c induced by exercise is due to an increase in the rate of synthesis and that the degradation rate is not significantly affected.

# CHAPTER III

## METHODS AND PROCEDURES

### Subjects

Twenty-eight healthy, active male volunteers ranging in age from 18 to 24 years were involved in a six week training program. All subjects were undergraduate students at the University of Alberta.

### Anthropometrical Data

Anthropometrical data collected from each subject was as follows: height (cm); age (years and months); lean body mass (kg); linear distance moved by the acromioclavicular process caused by extension at the ankle, knee and hip when the joint angle formed by the greater trochanter, lateral condyle of the femur and lateral malleolus of the ankle moves from an angle of $65^{o}$ (115) to complete extension. The $65^{o}$ angle is the angle of the femur relative to its vertical position.

### Equipment

The following equipment used in this study was checked and calibrated prior to each testing session:

- Cybex II isokinetic dynamometer
- Power rack
- Weights, Bar and collars
- Force platform
- Recorder system
- Goniometer
- Leg dynamometer

### Cybex II System

The Cybex II isokinetic system consists of three components:

(1) A Cybex II Dynamometer which measures torque inputs up to 360 foot-

pounds. The resistance supplied via the input attachment varies automatically to accomodate the fluctuating force applied by the subject. Any force against the input shaft is measured as torque on the input shaft and displayed on a front gauge dial. Because of the accomodating resistance mechanism in the apparatus, the velocity of an exercising limb cannot be accelerated. Instead, as more force is exerted against the lever arm of the apparatus, more resistance is encountered by the limb and movement occurs only at a present velocity of contraction;

(2) A speed selector which can be preset to obtain a constant speed of rotation of the lever arm from 0 to 300 degrees/second. Once a speed is selected, the lever arm cannot be accelerated beyond that speed regardless of the input torque applied below 360 foot pounds; and

(3) A fast response recorder and heated stylus which simultaneously produces and displays a permanent written record of the applied torque. (65)

<u>Power Rack</u>

The power rack was a large angle iron support frame for the barbell and weights which allows the subject to give a maximal explosive effort without the problem of supporting the weights while in an untenable or dangerous position. Use of the power rack also provided for attachment of a force platform which was connected to the recording instrument. The angle at which the lift was made was kept constant at $53^{o}$ with the horizontal by the construction of the power rack.

<u>Bar-Collars-Weight</u>

The bar and collars were standard. The weights were the standard

Weider weights as provided in the University of Alberta weight training room. The following breakdown provided for the maximum resistance requirement.

| Number | Weight (lbs.) | Total (lbs.) |
|---|---|---|
| 2 | 50 | 100 |
| 8 | 35 | 280 |
| 2 | 20 | 40 |
| 2 | 10 | 20 |
| | | 440 |

Force Platform

The force platform was a Stoelting force sensitive platform, catalogue number 19570. Although this platform has the capacity to monitor force vectors in three axes (X, Y, Z) only the Z or vertical axis was used in this investigation. The signal from the force platform was provided by an LVDT pickup.

Recorder System

Recording of data was accomplished by a Honeywell Electronic Medical System, model number 6793478-1. Parts of the system involved in this study were the 8011 oscilloscope, the model 530-X-Y recorder and the 1912 Visicorder. The recording paper used by the Visicorder is Kodak linagraph paper direct print, type 1895 standard.

Goniometer

A goniometer was used to adjust knee angle to $65^{o}$, measured from the vertical position, before the start of each exercise bout.

Leg Dynamometer

This instrument was used to measure the static strength of the knee extensor muscles. The dynamometer worked on the principle of tension

applied to a chain compressing a pair of plungers which in turn rotated a pointer over a calibrated scale. The dynamometer was mounted on a small elevated platform and was supplied with a metal handle 22 inches long, and a chain 24 inches long. The handle was taped to facilitate firm handling by the subjects. The measurement capacity of this instrument was 2500 pounds.

Initial Familiarization

The initial familiarization took place in three sites: rehabilitation medicine laboratory; strength and endurance laboratory; and the densitometry laboratory. All subjects met at each site prior to the pre-training test in order to familiarize themselves with the equipment and the routine that would be used.

Pre-Training Test

In the densitometry laboratory each subject was assessed for lean body mass which was used to set the resistance during the training program. The under-water weighing technique was used with body density measured and percentage body fat estimated by the formula of Brozek and Keys (11). Vital capacity was measured with a spirometer. Residual lung volume was estimated as 30% of vital capacity and the volume of the gastro-intestinal tract was estimated as 7.01 cubic inches.

Static leg strength was assessed by use of the leg dynamometer. The dynamometer was placed against a wall and the subject was instructed to keep his back flush against the wall when lifting, no belt was used. The scores for the leg dynamometer were recorded from the one maximal effort that the subject was able to attain in as many trials as desired. The face of the dynamometer was graduated in pounds, therefore all the raw data was transformed to kilograms by dividing the original score

by 2.2.

Each subject was tested on the Cybex dynamometer for power and dynamic strength of the knee extensor/hip flexor muscles as per Cybex testing protocol (22). The scores for the Cybex test at $30^{o}$/sec were taken from the one spike with the highest amplitude from the base line. A number of repetitions were allowed until it was obvious that the subject could produce no higher score. The measurement from the Cybex was in foot-pounds of torque, this measurement was converted to kilogram-meters of torque by multiplying the original number by 0.1383.

The data for the Cybex test at $180^{o}$/sec was obtained by selecting the quadriceps extension curve which gave the best combination of torque (ft.lbs.) and time (secs.) resulting in one highest power measurement in ft.lbs./sec. Peak torque was determined by selecting the curve with the highest deflection measured from the base line while the shortest time was determined by choosing the curve whose intercepts with the base line were as close together as possible. The maximum power measurement was multiplied by 1.356 to convert from ft lbs/sec to watts. The resultant measure in watts was divided by the lean body mass to arrive at a figure in watts/kg LBM.

To determine power output from the force platform and power rack system the subject was positioned on the force platform with a knee angle of $65^{o}$ with the vertical. A resistance equal to 150% of lean body mass was placed on the bar. The subject was given as many repetitions as required to record maximal mechanical power output. The data recorded for power output was obtained by correcting for the angle of the power rack and also for the angle at which the subject directed the resistance up the rack. This correction factor, appearing in

Appendix C, was a constant since the angle of the rack did not vary and the foot position of the subject upon the force platform was controlled. The correction factor in effect altered the angle of the lift so that it was recorded as if in the vertical plane.

The weights used for resistance were in pound units and the distance the load was lifted was measured in feet and tenths of feet to five a resultant work output in foot-pounds. The recording from the Visicorder allowed for the measurement of time for the leg extension phase of each repetition. With the result in ft lbs/sec and corrected for the angle of the lift and the angle of the rack the resultant was multiplied by 1.356 to convert to watts. This figure was divided by lean body mass of the subject to give a final recorded measurement in watts/kg LBM.

Vertical jump was determined by measuring the distance from the floor to the tip of the fingers with the arm extended maximally and the knees at an angle of $65^{\circ}$. The measurement was repeated with the subject maximally extended at the knee and plantarflexed at the ankle. The difference between these measurements was recorded as $h_1$. The height the subject could reach in a one-step vertical jump was measured by having the subject touch a pre-measured tape on the wall at the peak of the jump. The difference between the height of the maximal vertical jump and the measurement taken in the fully extended position was recorded as $h_2$. The subject was allowed as many repetitions as necessary to obtain a maximal recording for vertical jump height. This maximal recording was used for all subsequent calculations.

Formulas and calculations used to determine power manifest in the vertical jump are as per Appendix D.

Assignment of Subjects to Training Groups

The subjects were initially divided into two classifications - skilled (n = 14) and unskilled (n = 14). Each of these classifications were ranked for power output, as measured by the pre-test, from 1 to 14. The top 8 rankings were deemed high power and the bottom 6 rankings were deemed low power. The 8 high power subjects were assigned randomly to treatment groups. The order of selection was URG, VRG, control and then reversed until all of the 8 high powered subjects had been assigned. The 6 low powered subjects were assigned in the same manner except that the first assignment was to control group. In this way each cell for the training groups had 3 high powered subjects and 2 low powered subjects while the control groups had 2 high powered subjects and 2 low powered subjects in each cell.

Post-Training Test

The post-training test involved exactly the same measurements taken during the pre-training test.

Experimental Design

The experimental design used was a 2 X 3 X 2 factorial design (fixed model) with repeated measures on the last factor.

The two levels of the first factor (factor A) (classification) was the 2 blocks of 14 individuals into which the subjects were assigned based upon whether they were considered skilled or unskilled. These two levels were:

($a_1$) a group that participated in sports requiring vertical jump as a basic skill;

($a_2$) a group that did not participate in sports requiring vertical jump as a basic skill.

The three levels of the second factor (factor B) (treatments) to which the two levels of factor A were randomly assigned were:

($b_1$) a group initiating the training program by training with a resistance of 150% of LBM, 5 times per week;

($b_2$) a group initiating the training program by training with resistances of 150%, 50%, 100%, 50% and 150% of LBM during the first week;

($b_3$) a control group that does not perform resistance training.

The two levels of the third factor (factor C) (repeated measures) were:

($c_1$) the pre-training test scores; and

($c_2$) the post-training test scores.

Statistical Procedures

To determine whether the treatment groups for any of the dependent variables were initially statistically different from one another, one-way ANOVA's were run on the pre-test scores for the dependent variables. On the basis of these analyses, (Appendix E), it was determined that all treatment groups were equal at the beginning of the experiment and that it was permissable to analyse the data using ANOVA rather than ANCOVA.

Three-way ANOVA's with repeated measures on the last factor were run on the six dependent variables. Where significant ($p < .05$) F ratios were obtained for the interactive effects, a Scheffe procedure was used to compare the means of the individual group interactions from pre to post-test. An SPSS computer program was used to perform the three-way ANOVA's. This program accommodated the unequal sample sizes by performing computations using the unweighted means procedure.

In order to determine if there was any difference in performance

between the two training groups during the training program one-way ANOVA's were run on the force, velocity and power measures obtained from the training program.

The Training Program

The training program was as outlined in the experimental design. In addition, at the start of every week the resistance of exercise from the previous week was increased by 10% (i.e. 150% - 160%, etc.) to provide for an overload training effect.

CHAPTER IV

# RESULTS

Attrition was unusual in that three members were lost from the VRG, one from control group while none were lost from the URG. It was decided that a statistical analysis would be used that would allow for the unequal numbers in each group rather than to randomly exclude any of the subjects.

## Anthropometric Data

Measurements taken on the 28 subjects during the initial familiarization and pre-test are summarized in Table I and found in full in Appendix A. Subjects numbered from 1 to 24 completed the entire study including the post-test, while subjects numbered 25 to 28 completed only the pre-test and part of the training program.

TABLE I

ANTHROPOMETRIC DATA COLLECTED DURING PRE-TEST

| GROUP | AGE(YRS.) | HEIGHT(cm.) | BODY MASS(kg.) | LEAN BODY MASS(kg.) |
|---|---|---|---|---|
| URG | 20.5 $\pm$ 2.2 | 186.3 $\pm$ 9.6 | 78.6 $\pm$ 6.9 | 71.8 $\pm$ 6.9 |
| VRG | 20.1 $\pm$ 1.3 | 177.4 $\pm$ 10.4 | 74.2 $\pm$ 6.0 | 66.9 $\pm$ 6.5 |
| CONTROL | 20.5 $\pm$ 1.6 | 185.0 $\pm$ 7.8 | 76.8 $\pm$ 7.9 | 70.8 $\pm$ 7.5 |

## Raw Scores

Raw scores for the 24 subjects completing the entire study are found in Appendix B.

## Monitoring of the Training Program

During the training program a system was devised which made it feasible to record every exercise session for every subject. This system consisted of an X-Y recorder which had sufficient frequency

response to chart each lift and was compatible with the recording apparatus already in use. The recordings were on standard graph paper and thus became a permanent record of the entire training program from day seven to day thirty.

Because of the amplitude of spike obtained from each lift it was possible to record only three sets of the six completed on a daily basis. The sets recorded were selected randomly but the subject was aware that a recording was being taken due to the sound of the recorder being switched on.

The use of the X-Y recorder made it possible to measure force output and time for each repetition. The distance over which the force acted was taken as a constant which was previously measured for each subject. This allowed for the recording of average force (Figure 2), time (Figure 3) and power output (Figure 1) for every exercise session during the training program.

Figure 1 depicts the mean power output for the two training groups over the thirty day training program. The data from which the points of Figure 1 were plotted was grouped into three classifications as shown in Table II.

TABLE II

CLASSIFICATION OF EXERCISE RESISTANCE
FOR THE TRAINING GROUPS

| CLASSIFICATION | URG | VRG |
|---|---|---|
| I | Heavy exercise resistance | Heavy exercise resistance |
| II | Heavy exercise resistance | Medium exercise resistance |
| III | Heavy exercise resistance | Light exercise resistance |

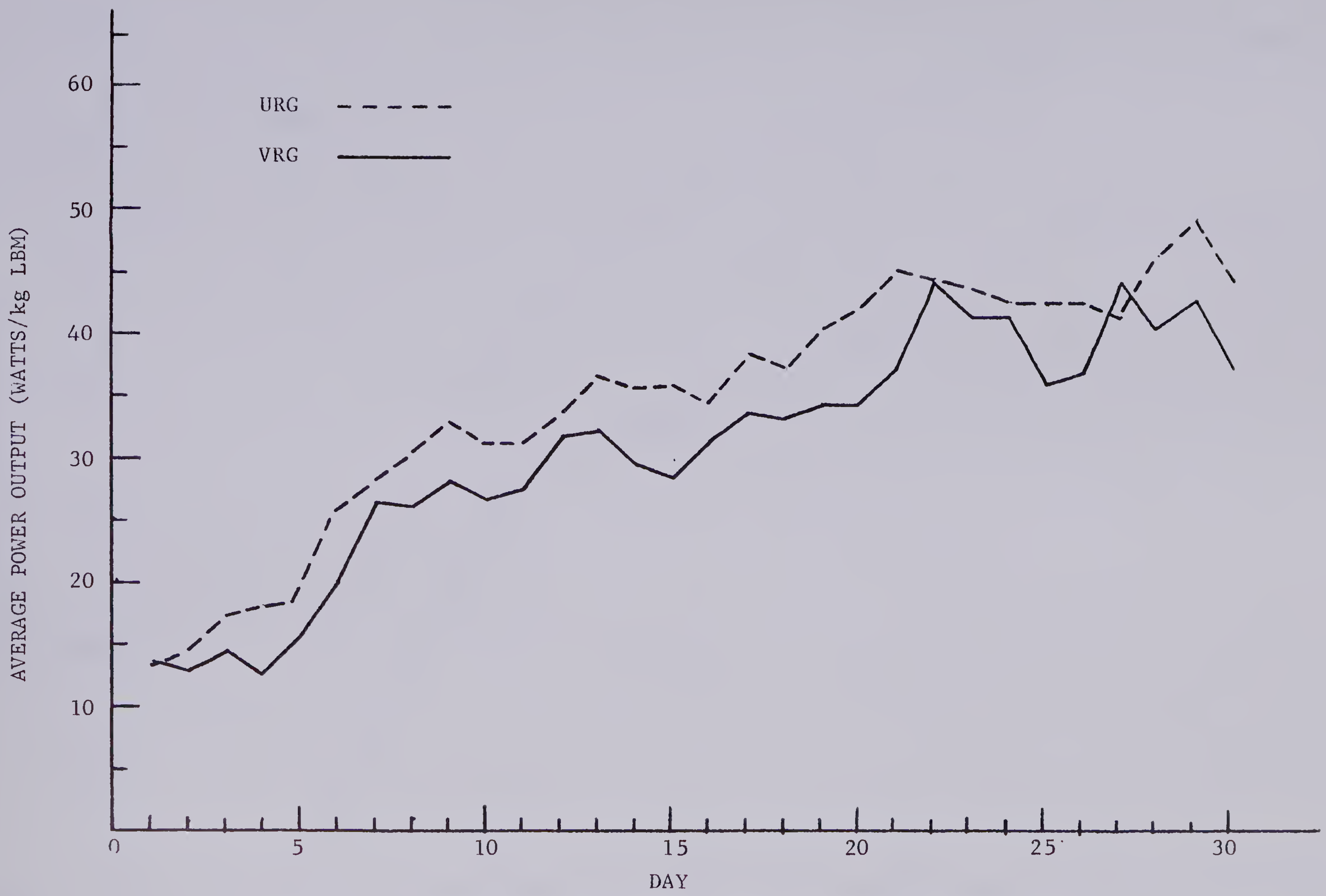


FIGURE 1. AVERAGE POWER OUTPUT DURING THE TRAINING PROGRAM

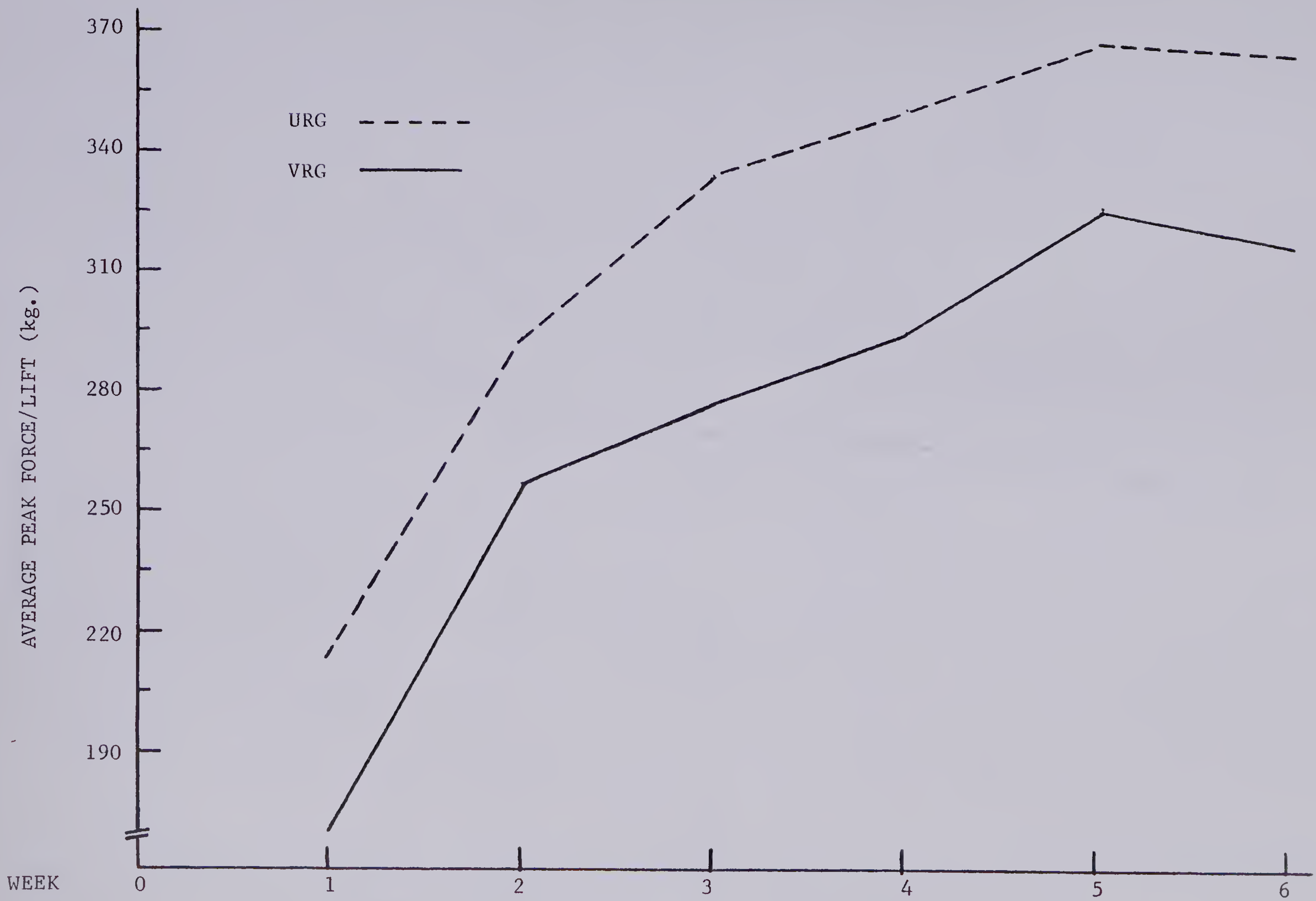


FIGURE 2. AVERAGE PEAK FORCE PER LIFT DURING EACH WEEK OF TRAINING

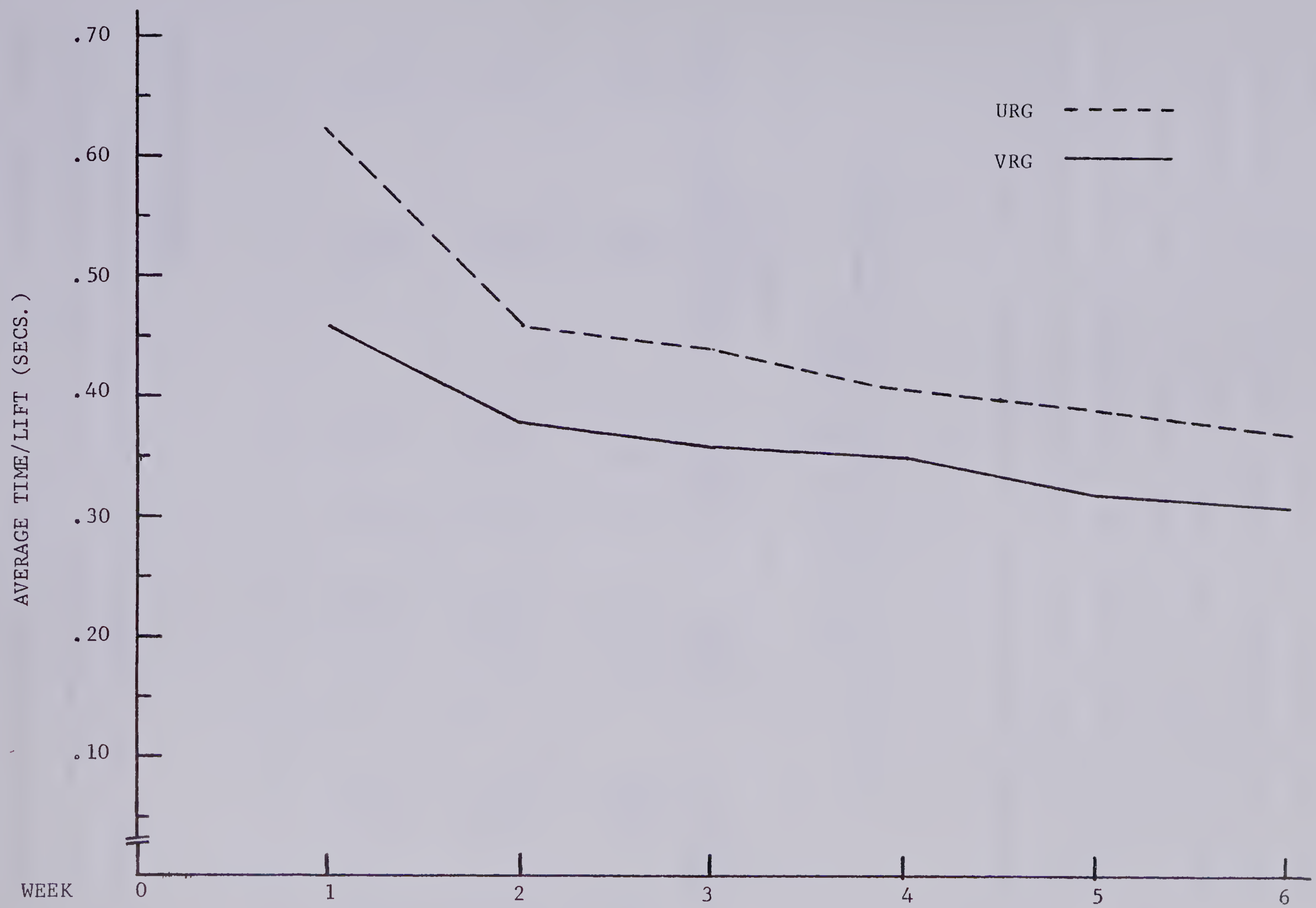


FIGURE 3. AVERAGE TIME PER LIFT DURING EACH WEEK OF TRAINING

Each of these classifications was analyzed using a one-way ANOVA (Table III, Appendix F-I). The results of the analysis showed that for both groups under all exercise resistance classifications there was no significant difference ($P < .05$) in power output. The data of Table III for average time per lift showed a significant difference ($P < .01$) under classification III (Appendix F-II). The ANOVA for data obtained for average peak force per lift from Table III showed a significant difference ($P < .01$) between the two groups under classification III (Appendix F-III).

TABLE III

AVERAGE TIME PER LIFT, AVERAGE PEAK FORCE PER LIFT AND AVERAGE POWER OUTPUT FOR THE TRAINING PROGRAM UNDER THREE CLASSIFICATIONS

| GROUP | EXERCISE RESISTANCE (CLASSIFICATION) | TIME (sec.) | FORCE (kg.) | POWER (Watts/kg LBM) |
|---|---|---|---|---|
| URG | MAX. | .42 ± .12 | 345 ± 23 | 38.81 ± 5.54 |
| VRG | MAX. | .41 ± .08 | 324 ± 20 | 32.89 ± 4.37 |
| % | (I) | VRG + 2.4 | URG + 6.3 | URG + 18.0 |
| URG | MAX. | .41 ± .08 | 345 ± 28 | 38.79 ± 6.25 |
| VRG | MED. | .34 ± .05 | 300 ± 30 | 34.75 ± 6.39 |
| % | (II) | VRG + 20.6 | URG + 15.0 | URG + 11.6 |
| URG | MAX. | .42 ± .09 | 352 ± 23 | 39.81 ± 5.27 |
| VRG | MIN. | .30 ± .04 | 272 ± 28 | 36.70 ± 6.47 |
| % | (III) | VRG + 40.0 * | URG + 29.4 * | URG + 8.5 |

* $P < .01$

## Static Leg Strength

Pre and post-test mean forces (± S. D.) exerted by the subjects on the leg dynamometer are shown in Table IV. Graphic illustration of this data is presented in Figure 4. The summary table for the three-way

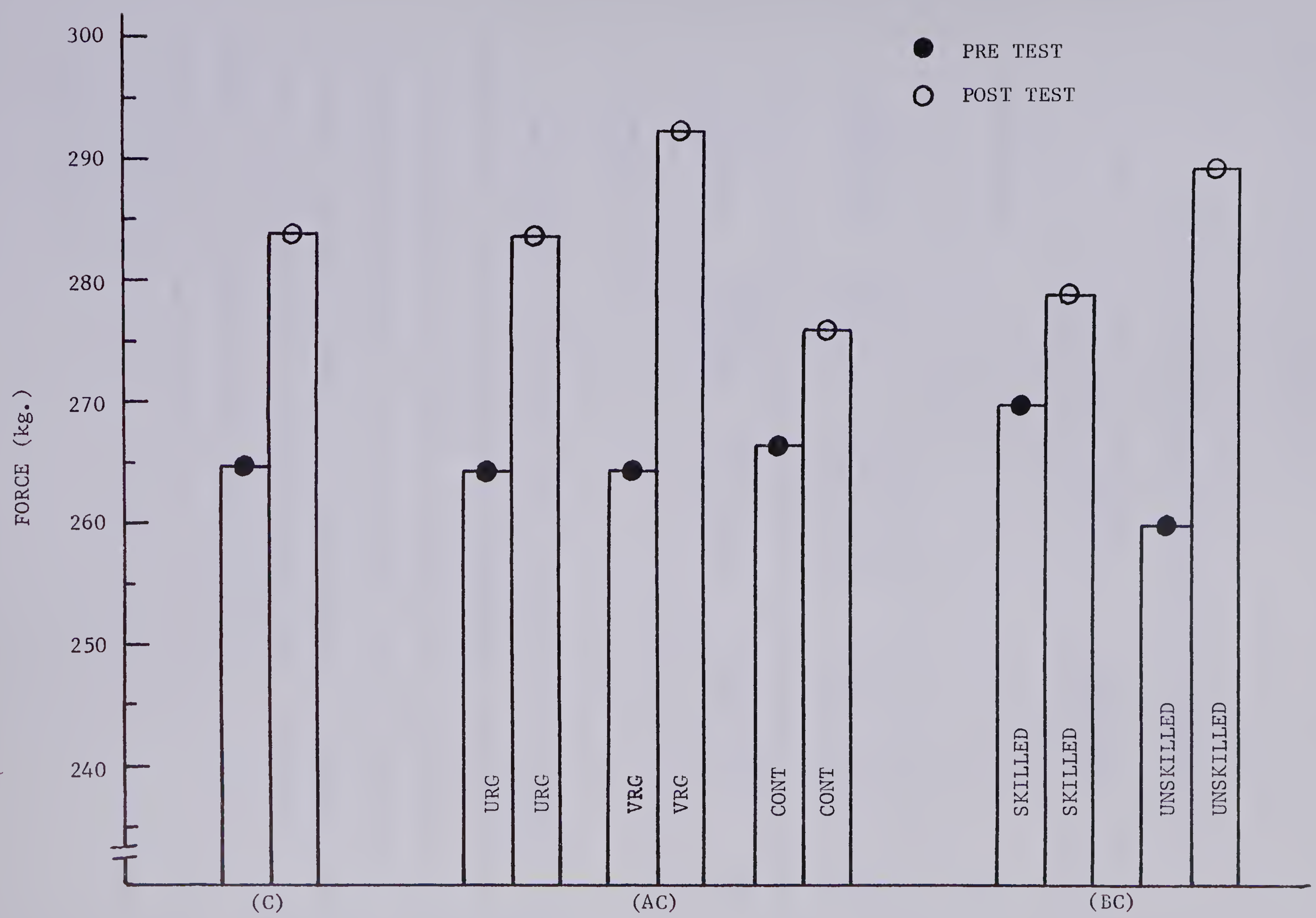


FIGURE 4. PRE AND POST-TEST MEANS FOR STATIC LEG STRENGTH

ANOVA performed on the data for maximal force exerted on the leg dynamometer is presented in Appendix G.

TABLE IV

PRE AND POST-TEST MEANS FOR STATIC LEG STRENGTH

| | GROUP | PRE-TEST MEAN* (±S. D.) | POST-TEST MEAN* (±S. D.) | Δ % |
|---|---|---|---|---|
| (C) MAIN EFFECT | | 264.8 ± 44.0 | 283.8 ± 44.7 | 7.2 ** |
| (AC) INTERACTION | URG | 264.1 ± 44.9 | 283.6 ± 48.2 | 7.4 |
| | VRG | 264.3 ± 54.1 | 292.1 ± 53.9 | 10.5 |
| | CONTROL | 266.2 ± 38.6 | 275.9 ± 33.6 | 3.6 |
| (BC) INTERACTION | SKILLED | 269.7 ± 43.3 | 278.7 ± 36.6 | 3.3 |
| | UNSKILLED | 259.8 ± 46.2 | 289.0 ± 52.8 | 11.2 |

* Measured in kg.
** $P < .02$

The analysis revealed significant ($P < .05$) pre-test post-test main effects (C). No other significant differences were found. The (AC) and (BC) interactions are of interest although they did not show a significant difference from pre-test to post-test. The (AC) interaction indicated that the URG improved 7.4% from pre-test to post-test while the VRG improved 10.5% and the control group 3.6%. The (BC) interaction showed a 3.3% increase in static leg strength for the skilled group from pre-test to post-test while the unskilled group had an 11.2% increase. The (C) main effect showed an overall increase from pre-test to post-test of 7.2%.

Dynamic Leg Strength

Pre and post-test means (± S. D.) for dynamic leg strength measurements from Cybex II dynamometer at 30°/second for the treatment groups are shown in Table V. Graphical representation of these data are shown in Figure 5. The summary table for the three-way ANOVA is shown in Appendix H.

TABLE V

PRE AND POST-TEST MEANS FOR DYNAMIC LEG STRENGTH MEASUREMENTS FROM CYBEX II DYNAMOMETER AT 30°/SEC.

| | GROUP | PRE-TEST MEAN* (±S. D.) | POST-TEST MEAN* (±S. D.) | Δ % |
|---|---|---|---|---|
| (C) MAIN EFFECT | | 17.8 ± 3.8 | 18.1 ± 3.8 | 1.8 |
| (AC) INTERACTION | URG | 17.5 ± 3.6 | 18.8 ± 4.6 | 7.2 |
| | VRG | 18.2 ± 4.5 | 17.5 ± 2.6 | -3.8 |
| | CONTROL | 17.7 ± 3.8 | 17.7 ± 4.0 | 0.0 |
| (BC) INTERACTION | SKILLED | 18.3 ± 4.5 | 17.8 ± 4.8 | -2.9 |
| | UNSKILLED | 17.2 ± 3.0 | 18.4 ± 3.0 | 6.8 |

* Measured in kg m

The analyses of the data revealed no significant differences. In reference to Table V the (C) main effect indicated a 1.8% increase from pre-test to post-test. The URG increased 7.2% while the VRG decreased 3.8% and control remained the same. The skilled performers showed a decrease of 2.9% while the unskilled improved by 6.8%.

Power - Cybex II at 180°/Second

Means of pre and post-tests (± S. D.) are shown in Table VI for power output measurements on the Cybex II dynamometer at 180°/second. Graphs of this data are shown in Figure 6. A summary table for the three-way ANOVA appears in Appendix I.

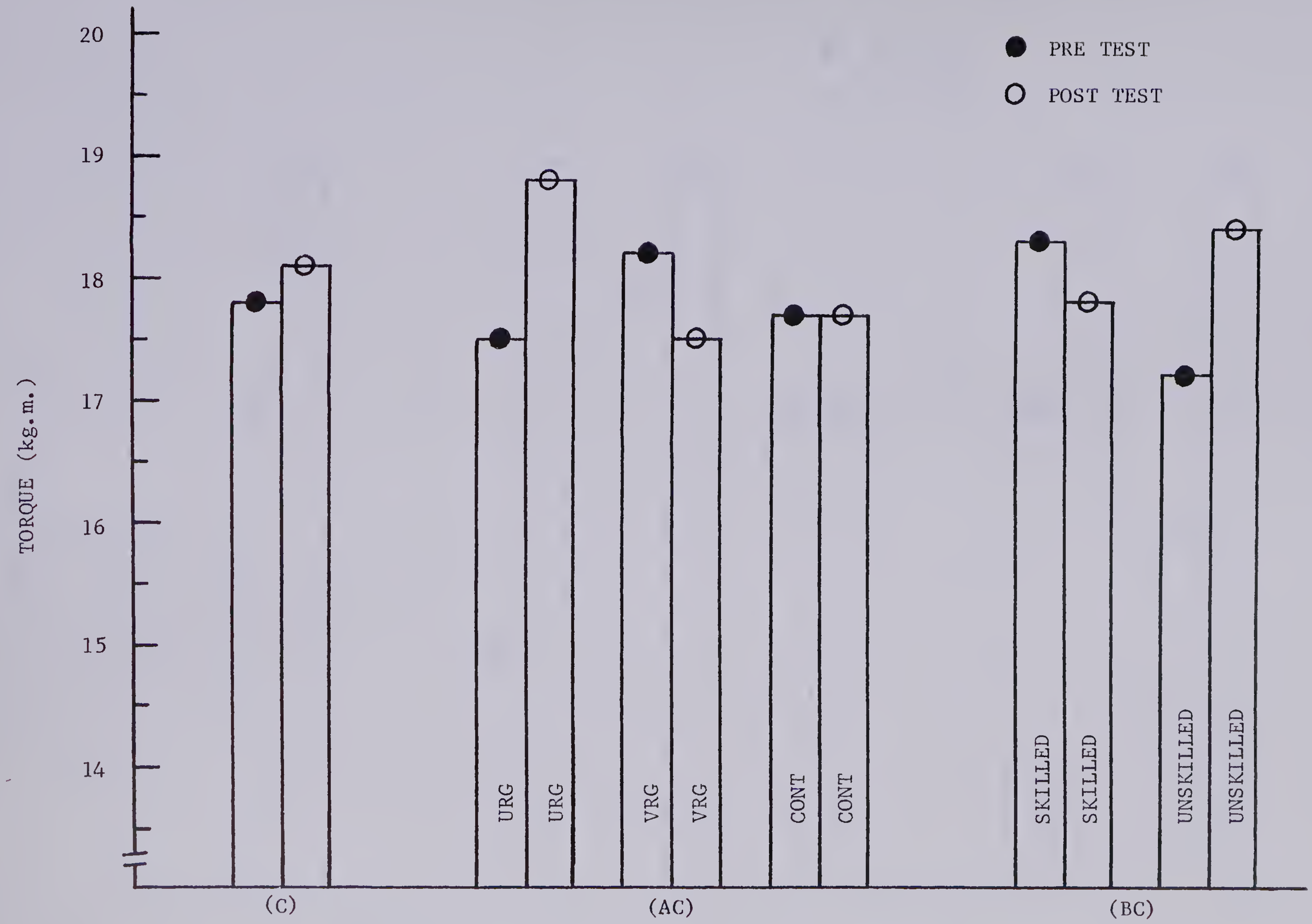


FIGURE 5. PRE AND POST-TEST MEANS FOR DYNAMIC LEG STRENGTH MEASUREMENTS FROM CYBEX II DYNAMOMETER AT $30^{o}$/SEC.

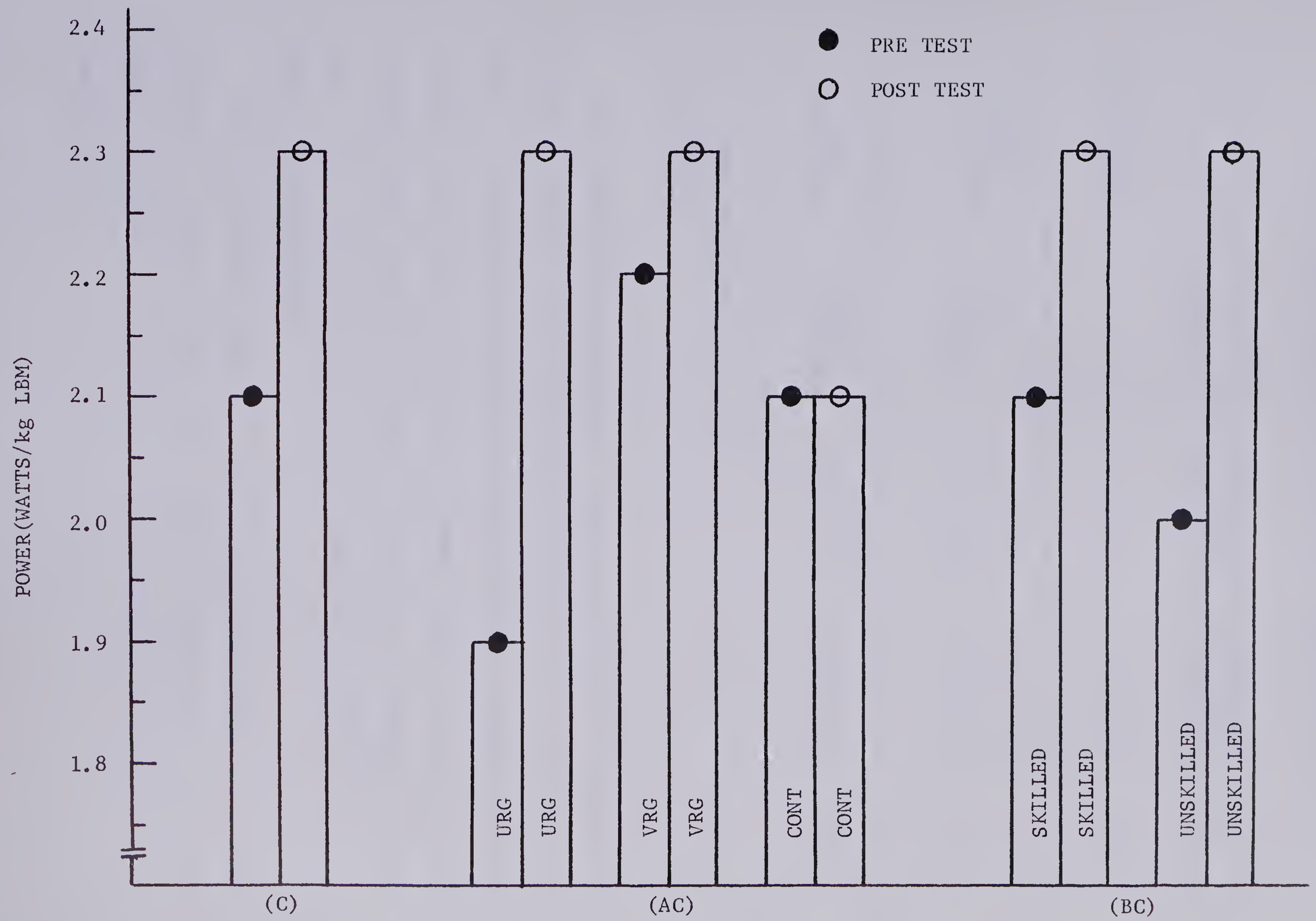


FIGURE 6. PRE AND POST-TEST MEANS FOR POWER OUTPUT MEASUREMENTS FROM CYBEX II DYNAMOMETER AT 180°/SEC.

TABLE VI

PRE AND POST-TEST MEANS FOR POWER OUTPUT MEASUREMENTS FROM CYBEX II DYNAMOMETER AT 180°/SEC.

| | GROUP | PRE-TEST MEAN* (±S.D.) | POST-TEST MEAN* (±S.D.) | Δ % |
|---|---|---|---|---|
| (C) MAIN EFFECT | | 2.1 ± 0.3 | 2.3 ± 0.3 | 10.5 ** |
| (AC) INTERACTION | URG | 1.9 ± 0.3 | 2.3 ± 0.3 | 21.0 |
| | VRG | 2.2 ± 0.4 | 2.3 ± 0.3 | 7.8 |
| | CONTROL | 2.1 ± 0.2 | 2.1 ± 0.3 | -0.1 *** |
| (BC) INTERACTION | SKILLED | 2.1 ± 0.4 | 2.3 ± 0.4 | 8.0 |
| | UNSKILLED | 2.0 ± 0.3 | 2.3 ± 0.3 | 13.3 |

* Measured in Watts/kg LBM
** $P < .005$
*** $P < .045$

The summary table indicates a significant ($P < .05$) treatment X time (AC) interaction. Also a significant ($P < .05$) main effect for (C) is shown. A Scheffe post hoc test of significance on the (AC) interaction revealed a significant ($P < .05$) difference between the pre-test measure for the uniform resistance group and the post-test measure for that group. The Scheffe produced no other significant differences.

Power - Force Platform

Pre and post-test means (± S.D.) for power output on the force platform are shown in Table VII. Graphic illustration of these data appear in Figure 7. The three-way ANOVA summary table appears in Appendix J.


FIGURE 7. PRE AND POST-TEST MEANS FOR POWER OUTPUT MEASUREMENTS FROM THE FORCE PLATFORM

TABLE VII

PRE AND POST-TEST MEANS FOR POWER OUTPUT MEASUREMENTS FROM THE FORCE PLATFORM

| | GROUP | PRE-TEST MEAN* (±S. D.) | POST-TEST MEAN* (±S. D.) | Δ% |
|---|---|---|---|---|
| (C) MAIN EFFECT | | 13.1 ± 3.8 | 43.1 ± 17.3 | 228.6 ** |
| (AC) INTERACTION | URG | 12.1 ± 4.9 | 55.1 ± 14.7 | 355.5 |
| | VRG | 13.8 ± 3.5 | 44.9 ± 9.4 | 192.7 |
| | CONTROL | 12.3 ± 1.7 | 24.1 ± 8.6 | 95.6 ** |
| (BC) INTERACTION | SKILLED | 13.3 ± 4.0 | 43.1 ± 17.9 | 223.8 |
| | UNSKILLED | 12.9 ± 3.6 | 43.1 ± 17.5 | 233.6 |

* Measured in Watts/kg LBM
** $P < .001$

The summary table indicates a significant ($P < .05$) treatment X time (AC) interaction. Also of significance ($P < .05$) are main effects (A) for treatment and main effects (C) for time.

A Scheffe test of significance performed on the (A) main effects describes a significant ($P < .01$) difference between the uniform resistance group and the control group and between the varying resistance group and the control group.

The (AC) interaction effects, when analyzed by a Scheffe test, showed significant ($P < .05$) differences between the pre-test and post-test scores for both the uniform resistance group and the varying resistance group. Also, both training groups showed a significant ($P < .05$) difference on the post-test when compared to the control group.

There was no significant ($P < .05$) difference on the post-test between the URG and the VRG.

Power - Vertical Jump

The means for pre and post-test ($\pm$ S.D.) power output from vertical jump are found in Table VIII. Graphic representation of these data appear in Figure 8. The three-way analysis of variance summary table for this variable appears in Appendix K.

TABLE VIII

PRE AND POST-TEST MEANS FOR POWER OUTPUT MEASUREMENTS FROM VERTICAL JUMP

| | GROUP | PRE-TEST MEAN* ($\pm$S.D.) | POST-TEST MEAN* ($\pm$S.D.) | $\Delta$ % |
|---|---|---|---|---|
| (C) MAIN EFFECT | | 80.7 $\pm$ 13.7 | 83.9 $\pm$ 13.4 | 4.0 ** |
| (AC) INTERACTION | URG | 81.5 $\pm$ 11.9 | 87.8 $\pm$ 12.6 | 7.6 |
| | VRG | 76.1 $\pm$ 18.1 | 78.4 $\pm$ 18.0 | 3.0 |
| | CONTROL | 83.9 $\pm$ 11.6 | 83.9 $\pm$ 8.0 | -0.1 *** |
| (BC) INTERACTION | SKILLED | 80.2 $\pm$ 11.5 | 83.9 $\pm$ 10.2 | 4.6 |
| | UNSKILLED | 81.1 $\pm$ 16.1 | 83.9 $\pm$ 16.5 | 3.5 |

* Measured in Watts/kg LBM
** $P < .016$
*** $P < .056$

The three-way analysis of variance shows a significant ($P < .05$) difference for (C) main effects. The treatment X time (AC) interaction has a probability level of .056 which did not meet the prerequisite significance level (.05). No other significant differences were found


FIGURE 8. PRE AND POST-TEST MEANS FOR POWER OUTPUT MEASUREMENTS FROM VERTICAL JUMP

for this variable.

Vertical Jump Height

Pre-test and post-test means (± S.D.) for height of vertical jump appear in Table IX. Graphic illustration of this data appears in Figure 9. The summary table for the three-way ANOVA for vertical jump height is found in Appendix L.

TABLE IX

PRE AND POST-TEST MEANS FOR VERTICAL JUMP HEIGHT

| | GROUP | PRE-TEST MEAN* (±S.D.) | POST-TEST MEAN* (±S.D.) | Δ % |
|---|---|---|---|---|
| (C) MAIN EFFECT | | 56.3 ± 6.6 | 57.9 ± 6.7 | 2.8 ** |
| (AC) INTERACTION | URG | 56.3 ± 6.1 | 58.8 ± 5.4 | 4.5 |
| | VRG | 53.3 ± 10.7 | 55.2 ± 10.4 | 3.4 |
| | CONTROL | 59.3 ± 3.7 | 59.3 ± 2.9 | 0.1 |
| (BC) INTERACTION | SKILLED | 58.8 ± 5.9 | 60.6 ± 4.6 | 2.9 |
| | UNSKILLED | 53.8 ± 8.0 | 55.3 ± 7.6 | 2.7 |

* Measured in cm
** P .008

The three-way analysis of variance indicated significant ($P < .05$) main effects (C) from pre-test to post-test. The (AC) interaction had a probability level of .088 which did not reach the critical level of significance (.05) predetermined for the dependent variables therefore no post hoc analysis of this variable was carried out. However, the height of vertical jump did increase 4.5% for the URG, 3.4% for the VRG

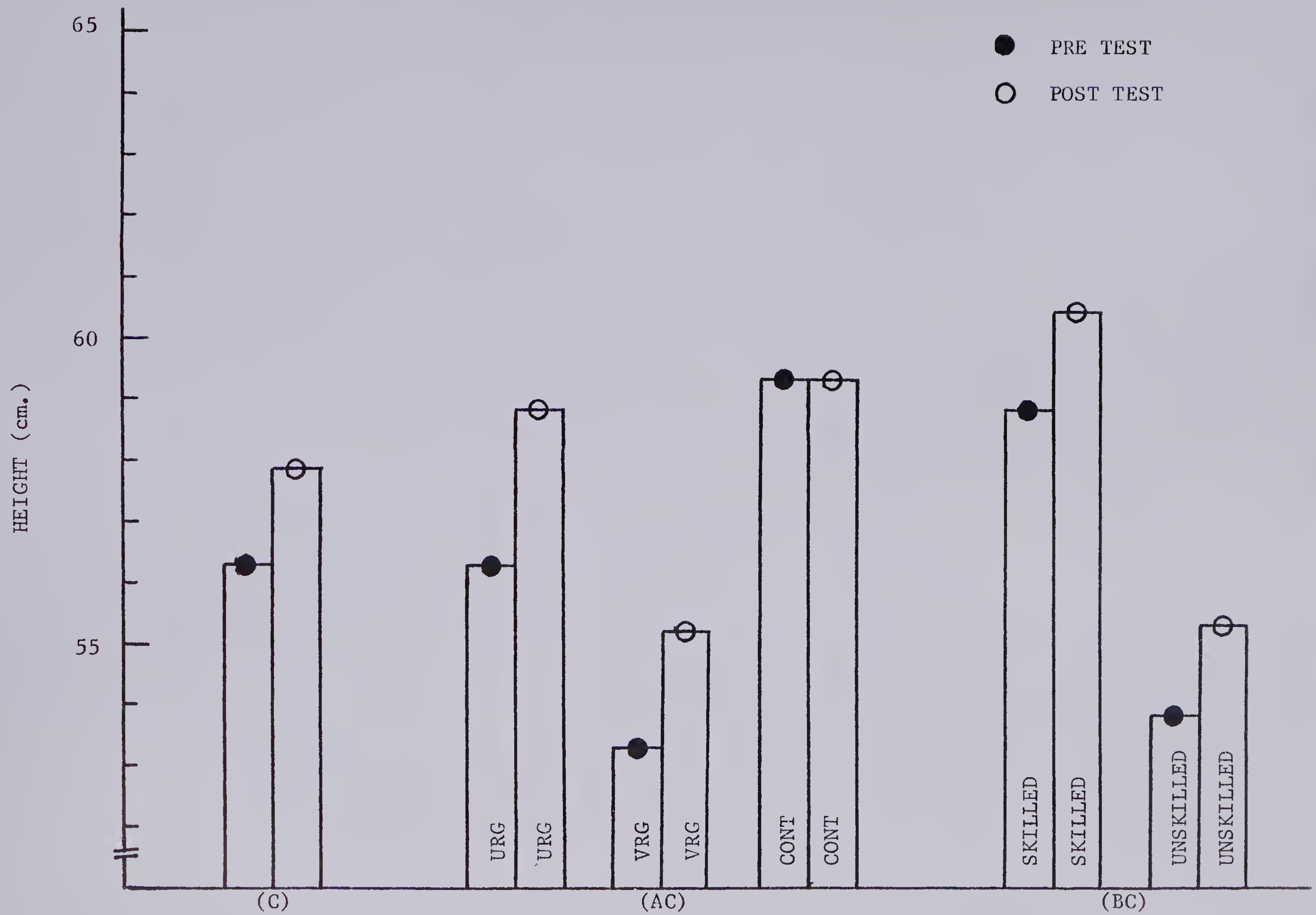


FIGURE 9. PRE AND POST-TEST MEANS FOR HEIGHT OF VERTICAL JUMP

and 0.1% for the control group. The skilled and unskilled groups showed a nearly equal increase of 2.9% and 2.7% respectively.

## CHAPTER V

## DISCUSSION

Upon inspection of the results obtained from the training program (Figures 1, 2, 3 and Table III) it is evident that the URG showed increased force output during the training program while the VRG produced greater velocity. The ultimate effect of these differences was that the two groups were equal in power output.

Inspection of the power output graph (Figure 1) shows that, after the first week, there were two days when the varying resistance group were practically equal to or exceeded the uniform resistance group in power output - days 22 and 27. Both of these days were light resistance days for the VRG which were immediately preceded by heavy resistance days. The days of greatest difference between the two groups in power output were heavy resistance days for the VRG immediately preceded by light resistance days - days 15, 20, 25 and 30. This pattern seems to be consistent for the entire training program.

The ramifications of this observation suggest that the VRG may have achieved their greatest power output, not as a result of a mechanical change in the muscle fibers to exert more force, but as the result of a neural recruitment pattern change which facilitated attaining the threshold of the FT fibers thus allowing a significantly higher contractile velocity of the muscle under the conditions of light resistance. If there had been a functional physical change in the muscle of the VRG to contract more forcefully the wide differences on heavy resistance days preceded by light resistance days would not be expected.

To further substantiate this observation a one-way ANOVA was employed to analyze the differences in power output, force and time for the VRG on

on light resistance days preceded by heavy resistance days as opposed to heavy resistance days preceded by light resistance days (Appendix M-I, II, III). The only significant ($P < .01$) difference found was for time. The VRG was significantly faster per lift than the URG on light days. Power output and force output were not found to be of a significant difference. This suggests the importance of the time factor in development of power output.

The high power outputs of the VRG for days 22 and 27 could be explained by considering the exercise resistance of a light day as opposed to the exercise resistance of a heavy day. During the first week of training the subjects of the VRG were exercising at resistances of 105% of lean body mass on heavy days and 50% of lean body mass on light days. The average resistance for this week was 266.7 pounds on the heavy days and 76.4 pounds on the light days. Expressed in percent from the light day resistances were 33.7% of the heavy days resistances. By week five the resistances have increased to 190% and 90% for heavy and light days respectively. Light day resistances are 47.7% of the heavy day resistances. In week six the relationship of light day to heavy day resistances has been altered to 49.9%. This may indicate that by days 22 and 27 the VRG was exercising in a more optimum range of the force-velocity curve for power output. It has been suggested that two-thirds of maximal resistance provides the optimum resistance for power development (53,61, 95,111). The improved power output on these days may be a reflection of this fact as the VRG subjects near the optimal resistance range.

Static Leg Strength

The results of the static leg strength test show a significant difference for the (C) main effects only. Upon further dissection of the data into (AC) and (BC) interactions some interesting factors are suggested.

The (AC) treatment X time interaction shows the highest mean difference for the VRG with a 10.5% increase while the URG increased 7.4% and the control group 3.6%. The fact that the VRG had the highest increase and exercised significantly faster during the training program while the URG exercised significantly more forcefully suggests that there may have been different types of muscle fibers trained by each group. It has been shown that FT muscle fiber is recruited in situations of high tension, high contractile speed or complete fatigue of the ST fibers (48,99,110,117). Others, when considering static versus dynamic contractions, have interpreted this information to mean that there are differences in the motor recruitment patterns (16,49).

The high tension of a maximal static contraction may reach the threshold for FT fibers. This would suggest that because the VRG had trained FT fibers by overloading velocity they were able to recruit some of the same fibers in a high tension (static) situation. The converse situation would not seem to be true in that the URG overloaded force output during training and yet when high tension was required in the static leg strength test they could not produce as much tension as the VRG. This observation suggests a priority in recruitment ordering, i.e., FT fibers have a lower threshold for high contractile velocity than for high tension output. Therefore the VRG was able to recruit some of the FT fibers in a high tension effort while the URG could recruit a lesser number.

The (BC) classification X time interaction elucidates two main points with regard to the performance of skilled versus unskilled subjects. Firstly, the advantage possessed by the skilled subjects is their expertise in performance of vertical jump. This is not a signif-

icant factor in performance of four of the six dependent variables and, as shown by comparison of Tables IV to IX for each dependent variable, the skilled subjects did not perform as well as the unskilled subjects on the four non-vertical jump oriented variables. Secondly, the skilled subjects, although not maximally strength trained, are closer to an optimal functional level of strength solely by participating longitudinally in their sport. It would be expected that the skilled people would produce a reduced relative change in performance for this reason.

Specific to performance in static leg strength the unskilled subjects responded with an 11.2% increase while the skilled subjects increased by 3.3%. The factors as already noted would provide some explanation of the variance. In addition, the potential for injury by use of the table dynamometer is considerable. Nine of the twelve skilled subjects were actively involved in basketball at the time of the test and all were aware of noticeable stress upon the knees. This may have had some effect on the results since sequellae of injury to the skilled subject would produce more serious ramifications than to the unskilled.

Dynamic Leg Strength

The results obtained in this study of dynamic strength are in close agreement with the results of Perrine and Edgerton (93). In their study maximal torque forces at $30^{o}$ before full leg extension were measured for fifteen males and females, 18 to 38 years old and from various activity patterns from sedentary to athletic. The peak of the range of torque values of the present study exceeded those of Perrine and Edgerton by 9% so essentially they are in agreement.

A study of the relationship of muscle fiber characteristics and muscle strength measured as a peak torque during isokinetic knee exten-

sion for a population of top Swedish athletes was compared to results of the present study. The results of Thorstensson et al (110) revealed a 12.5% higher average for track and field athletes than the peak of the range in this study. The peak of the range in this study exceeds the mean for their measurements on downhill skiers by 5%.

The results of the present research show an overall increase of 1.8% in dynamic strength which is non-significant. The small increase would suggest that the test speed of 30 degrees/second is considerably slower than the training speed of the subjects. Consequently an insignificant difference in knee extension strength was found.

A non-significant but interesting difference was found between the two training groups at this speed. As can be seen from Table V and Figure 5 the URG increased 7.2% while the VRG decreased 3.8%. A possible explanation for this result would be the same as hypothesized for static contractions; i.e. different fiber types are recruited by each group. This being a slow speed measure the group that had trained at the slower speed showed the advantage due to having trained a slower type muscle fiber. This partially explains the difference between the two groups but not the VRG decrease. This phenomenon has also been recorded by Jones (65) who showed an actual decrease in force from pre-test to post-test in females isokinetically training the elbow flexors. He found that of the individuals initially classified as high power producers 93% had lower force readings on the post test at peak MMPO, the same 93% had higher velocity measurements. In another training group initially classified as lower power producers 43% had lower force readings at peak MMPO on the post-test while 86% had higher velocity readings.

Moffroid et al (84) with a mixed group of males and females, isokinetically trained the knee extensors over a six week period. The two training groups were differentiated by their speed of exercise; Group I deemed the low power group trained at a slow speed ($36^{o}$/sec) while Group II deemed the high power group trained at a high speed ($108^{o}$/sec). The results showed that the low power group increased its force output by 32% at $36^{o}$/sec while the high power group increased its force output by 20% at $36^{o}$/sec.

This finding is supported by a study by Gordon and Kowalski (44) whose work involving forceful static and dynamic contractions in rat quadriceps resulted in an increase of concentration of myofibrillar protein and a decrease in sacroplasmic protein. They concluded that there is: 1) an actomyosin hypertrophy from forceful, strength-building exercises; and 2) a sarcoplasmic hypertrophy from repetitive, low-force, endurance provoking exertion.

From these examples it can be hypothesized that the VRG is similar to the high power groups and the sarcoplasmic hypertrophy group. The VRG shows more advantage in velocity than force (Table III) and possibly more sarcoplasmic than actomyosin hypertrophy. As previously noted in the discussion, during the training program the VRG had greater power outputs on light days preceded by heavy days as opposed to heavy days preceded by light days. It was hypothesized at that time that there seemed to be no mechanical functional change in the muscle to exert more force (actomyosin hypertrophy) but that there was some neuromuscular adaptation. This neuromuscular adaptation which is selectively recruiting the higher threshold FT fibers may in some way be affecting the activation of ST fibers which could in turn cause a decrease in low speed

force output.

Power - Cybex II at $180^{\circ}$/second

The format used for isokinetic power measurements in this study is the Cybex testing protocol. The test involves 4 or 5 maximal knee extensions and flexions consecutively with no rest between repetitions. The emphasis in the test is on speed of movement more than force output. In comparison with the study of Perrine and Edgerton (93) the format differs significantly. Their method required that power be measured from one maximal effort with a rest between trials. They emphasized the force of movement as well as speed.

Perrine and Edgerton showed that peak power of the knee extensors is found in the range of $240^{\circ}$ to $250^{\circ}$/second. This finding detracts from the usefulness of the protocol used for the older model Cybex. Osternig (88), with a Cybex that was capable of only 25 RPM ($150^{\circ}$/sec), plotted a power curve that was not plateaued when the capacity of the machine was reached.

Possibly because of the difference in format the range for subjects in this study measured on knee extension at $180^{\circ}$/second fell in the bottom 35% of the range found at the same speed by Perrine and Edgerton (93).

Comparing with measures of peak torque at $180^{\circ}$/sec as measured by Thorstensson et al (110) for top calibre Swedish athletes their range was from 1.7 Nm/kg bw for race walkers to 2.7Nm/kg bw for track athletes which included 1.9 Nm/kg bw for sedentary subjects. Using the same computations the group mean for the subjects of this study was $1.56 \pm .23$ Nm/kg bw.

The (C) main effect showed a significant ( $P<.05$) increase in power of 10.5%. The significant result may be due to the velocity of the test being closer to the specific velocity range of the training program than was the velocity of the dynamic strength test at $30^{\circ}$/sec.

In reference to Table VI and Figure 6 the (AC) treatment X time interaction was significant ($P<.045$). The URG increased by 21.0% while the VRG increased by 7.8%. A post hoc test of significance showed that the only significant difference was for the URG from pre to post-test.

It is possible that $180^{\circ}$/sec is the optimal velocity for the URG while the VRG, although improved in performance over the $30^{\circ}$/sec measure, has not reached their optimal-velocity zone of peak performance. At velocities in the vicinity of 240 to 250 degrees per second peak power would be expected as previously shown by Perrine and Edgerton (93).

Based on the observation of optimal velocity zone of $180^{\circ}$/sec for the URG it is possible that the URG has trained an intermediate type of muscle fiber or a more heterogenous mixture of fibers. Previous evidence from static strength measures and $30^{\circ}$/second isokinetic measures tend to support this view.

In reference to Figure 6 it can be seen that a large disparity exists in pre-test power levels between the training groups. Therefore the final levels attained in the post-test may indicate a maximizing of the potential of both groups to generate power at this velocity. The groups are equal on the post-test but the relative degree of change for the URG was significant whereas the change in VRG performance was considerable but not significant.

Power - Force Platform

The measurement of power output by use of an isotonic device (power rack) in conjunction with the force platform presents unique aspects which have not been widely considered in previous studies involving isotonic training of the knee extensor musculature. Other researchers have studied increases in strength involving similar techniques of isotonic training but were not as concerned with the velocity of exercise (17,20,108,116). In this regard, by isolating the force involved in power output measurements from pre and post-test, it is possible to gain some insight into the magnitude of forces involved in a training program for power and a training program for strength using the same format of training.

Thorstensson et al (108) and Coleman (17) used a one repetition maximum (1 RM) criterion to measure increases in knee extensor strength after an isotonic training program; they found 67% and 18% increases respectively. The average increase in force output as calculated from the force platform power measure of this study revealed a 71% increase. Wilmore (116) found an increase in strength of 26% and 29.5% for men and women respectively after a 10 week training program as measured by a leg dynamometer with belt. Although the methods of measurement and the specific objectives of the programs vary the results in ability of the knee extensor muscle group to exert a force are comparable. The lower percentage increases of Wilmore and Coleman could be a reflection of training isotonically and measuring isometrically in the first case and in the second case using a training group that was initially stronger than subjects of comparable studies.

Considering the present study the (C) main effect of a three-fold increase in power output demonstrated via the power rack is not to be unexpected since this was the training vehicle for this study. As shown in the results the (A) main effect for treatments, the (C) main effect for time and the (AC) treatment X time interaction were all highly significant ($P < .001$).

The (AC) treatment X time interaction interestingly depicts a direct reflection of the magnitude of load volume employed by each of the training groups through the training program. The total cumulative load volume lifted by the VRG was 66.6% of the volume lifted by the URG. In accordance with this factor the VRG developed 68.8% as much power increase as did the URG. The ratio of load volume lifted to amount of power gain is 1:1.

The (A) main effect for treatments, considered singularly, is misleading in that it seems the VRG has approximately 90% of the power of the URG. In actuality by absolute terms this is true, but, by negating the 27% higher power measure of the VRG in the pre-test the training program alone accounts for the 1:1 relationship of load volume to power increase as previously noted.

With reference to Figure 7 which graphically illustrates the (BC) classification X time interaction it can be seen that both classifications responded identically to the training stimulus by increasing power output equally. Physiologically this is evidence that what is termed by Selye (101) as "Specific adaptation to imposed demands" is occurring in both groups. The specific adaptation is increase in power output but the imposed demands are of differing sources. It is hypothesized that the skilled group is increasing the velocity of movement while the unskilled

group is increasing its ability to exert force with the net outcome of equal increase in power output as per the criterion measure.

Vertical Jump

A variety of studies have been undertaken involving the assessment of vertical jump which reflects the functional ability of the individual to manifest power through the knee extensor muscle group. Since the first such power tests were performed by Sargent (100) many have gone on to modify the technique but the basis of the test remains unchanged. The present study has used the basic technique of measuring power from vertical jump but has innovated a different unit of expression, i.e. Watts/kg LBM.

The findings of this study show a mean power output for vertical jump of 87.8 Watts/kg LBM for the URG and 78.3 Watts/kg LBM for the VRG. In order to compare these results with the research of others it was necessary to convert their data to the appropriate unit of expression. In some cases this involved assumption of a percentage of LBM when not provided in the anthropometrical data of the study. Thorstensson et al (108) with a population of 14 male physical education students who were trained by similar isotonic techniques used in this study show an average power output of 75.3 Watts/kg LBM. By use of a force platform Davies and Rennie (23) were able to measure power from vertical jump which they expressed as an average of 5.23 horsepower. This result converts to a power output of 57.9 Watts/kg LBM with an assumed percentage of body fat of 10% for males. Maximal heights of vertical jump for all of these studies closely agree with the present findings with the exception of the measurements taken for the women's volleyball team which was 7 cm less than the average for the training groups of this study.

The information from vertical jump data for power and for height is more cogent if examined simultaneously. Further discussion therefore will pertain to data found in Tables VIII and IX and to illustrations of respective data in Fugires 8 and 9.

The (C) main effect for time depicts a significant increase in power ($P < .016$) and also for height increase ($P < .008$).

According to the decision rule employed in this study the (AC) treatment X time interactions for both vertical jump power and vertical jump height were not significant at the .05 probability level. Vertical jump power revealed a significance level of .056 which reflected an increase of 7.6% for the URG and 3.0% for the VRG. Increases of 4.5% for the URG and 3.4% for the VRG in vertical jump height reached a significance level of .088. In reference to data obtained from the respective tables (VIII and IX) the absolute increase in power for the URG was 6.21 Watts/kg LBM and for the VRG an increase of 2.25 Watts/kg LBM. The mean increase in vertical jump height was 2.54 cm and 1.83 cm for URG and VRG respectively. By dividing the amount of power increase in Watts/kg LBM by the amount of height increase in centimeters a quotient is derived which suggests the relative efficiency of each of these systems in obtaining increases in vertical jump performance. The results of these calculations show the URG developing 2.44 Watts/kg LBM/cm of height increase. The VRG reveals a somewhat lower figure of 1.23 Watts/kg LBM/cm. The importance of this observation is that the URG must develop 98% more power to effect the same increase in height as the VRG. The physiological implication is an apparent facilitation of recruitment and training of low threshold ST fibers by the URG which are less efficient in terms of the amount of return in functional performance for

the amount of increase in absolute power.

This finding adds credence to the hypothesis of Odum and Pinkerton (86) that "natural systems tend to operate at that efficiency which produces a maximum power output".

The primary purpose of this investigation was to evaluate the effect of varying exercise resistance on the development of power in the knee extensor/hip flexor muscle group.

During the training program the effect of varying the work load was to show a predisposition for force production by the URG and a predisposition for velocity production by the VRG with the net outcome being equality in power development. This result is evident in the data of Table III.

As a result of varying work load maximal isometric force was increased to a greater degree in the VRG as opposed to the URG. This effect is hypothesized to be the result of the VRG having recruited and trained a higher percentage of FT fibers which are more directly recruited in a static high tension performance.

The effect of the training program upon the isokinetic measurements indicated a specificity of peak performance in an optimal velocity zone which through training became differentiated for the two groups. The reason for the differentiation, once again, probably lies in the specificity of fiber recruitment by each group.

The isotonic measurements from the force platform reveal a highly significant (AC) treatment X time interaction ($P < .001$). However the effect of varying exercise resistance resulted in no significant difference between the two training groups for power output. The power data from Table VII was divided into its force and velocity components

and these were compared for the URG and the VRG both at pre and post-test by t-test (Appendix N-I, II, III, IV). The only significant difference found was that the VRG had a greater velocity per lift than the URG for the pre-test. It appears that there is not only a 1:1 ratio of load volume lifted to power increase but also an equalization in velocity production between groups. It must be noted that the post-test was conducted with a resistance equal to 150% of LBM which would be advantageous to the URG. If the test had also been conducted at 50% of LBM where velocity would have been a more crucial factor than force there may have been an advantage in favor of the VRG.

It appears that the major effect of the variation in training was to recruit and train different types of muscle fibers to accomplish the same ultimate purpose. As was previously shown from the vertical jump data the URG had to produce 98% more power to effect the same increase in vertical jump height. In terms of power, force and velocity there is no difference between the groups at the resistances and velocities used for testing in this research quantitatively; but there is possibly a difference qualitatively.

A sub-purpose of this study was to ascertain the effect of varying exercise resistance on the process of restitution through protein synthesis after maximal resistance exercise. In this regard five sessions per week were used in an attempt to force the situation of increased protein catabolism due to exercise. It was expected that as the protein catabolism effects started to accrue they would manifest themselves in the form of a plateau of force increase and possibly even some decrease for the URG. At the same time it was expected that the VRG would continue to increase since they were allowed periods of reduced load with the

intention that they would show restitution or "super-restitution" of the muscle tissue. The data represented in Figure 2 for force output during the training program indicates that at week 5 there may have been a plateau but the plateau was for both groups which was not expected. If the program had been ten to twelve weeks in duration a plateau and decrease may have been more evident for the URG with a continuing positive slope of force gain for the VRG. The length of the program in this investigation was too short to make any statements about the effect of protein resynthesis other than it did not seem to have any effect on force output over the six week period.

Another sub-purpose of this research was to determine if varying the exercise resistance for one treatment group had any effect on the development of power in skilled versus unskilled individuals. One immediate problem that came to the forefront was that although the unskilled people were not involved in a sport requiring jumping ability, ten of the twelve unskilled subjects were physical education students which meant that they had some degree of athletic prowess.

The general reaction to the training stimulus seemed to favor the unskilled individual as can be seen from Tables IV, V, VI and VII. The skilled subjects seemed to have the advantage in measurements involving vertical jump. It was hypothesized that due to the technical skill of the skilled subjects they were better able to incorporate even small increases in knee extensor/hip flexor power into more significant increases in vertical jump height and vertical jump power than were the unskilled subjects.

## Implications and Inferences

Implications for coaching would be as follows. When initiating a

training program for power development the initial concern is to provide a solid base of strength upon which to develop speed. During the preliminary stage of a training program the greatest returns in power are by increasing force output. When force gains show a plateau a varying resistance type of program should be initiated. A varying resistance program will facilitate attaining two objectives. First, if maximum velocity per repetition is stressed it will recruit and train a larger percentage of FT fibers which are beneficial in high power performances. Second, it will allow for restitution and super restitution of the actomyosin components of the muscle between maximal resistance training bouts. This effect has been shown to occur (97,113) in well trained athletes who are approaching maximal performance capabilities.

From the experience of this research it is suggested that an effective varying resistance power program would involve four training sessions per week. The sequence of loads on a daily basis would be heavy, light, rest, heavy, light followed by two days of rest and then starting the sequence over again. In terms of intensity of load for a light day Vorobjev (113) states that the load should be sufficient to maintain the positive changes that will stimulate anabolism. The threshold for anabolism will obviously vary among individuals. Definition of precisely where the threshold for anabolism of skeletal muscle is found is beyond the scope of this thesis.

Concerning skilled versus unskilled athletes there may be some benefit to starting unskilled athletes on a resistance program which emphasizes strength building as well as technique. In this way as the athlete gains in strength and skill the newly acquired strength levels are being incorporated into proficient game skills. As the athlete approaches a plateau for strength development it would be reasonable to

assume that velocity training and variation of load would have a much greater impact. The skilled athlete who has not been involved in resistance training may have more difficulty in assimilating any strength gains into functional performance. Therefore the skilled athlete should be employing resistive exercises which involve velocities that would be typical of the game situation and also in specific movements which are intrinsic to the game skills. The training calendar for either the skilled or the unskilled athlete should schedule the heavy resistance weight training for the first part of the off-season. The latter part of the off-season, or what might otherwise be known as the pre-season, would probably be most efficiently spent in a varying resistance program emphasizing speed of movement and practice of technical skills.

Recommendations

Further experimentation is necessary before absolute statements can be made to substantiate the findings of this study, especially the effects of a longer training program. Also further experimentation is needed to confirm or reject the effectiveness of initiating the training program at 150% of LBM and increasing by 10% per week. A greater training stress in terms of resistance and increments may be more effective than those used in this study.

Subsequent to contemplation of the data gathered on all the dependent variables some subjective interpretation may prove pertinent. The performance of the skilled group seemed to mimic the VRG performance while the unskilled group resembled the URG. These groupings seem to respond to the training stimulus in the same way which suggests that skilled subjects responded better to speed and resistance training as does the VRG; the unskilled subjects responded to slower more forceful

training as does the URG. This trend between training groups provides groundwork for further research.

# CHAPTER VI

## SUMMARY AND CONCLUSIONS

The purpose of this investigation was to determine the effect of varying the resistance of exercise upon the development of power in the knee flexor/hip extensor muscle group. A sub-purpose was to determine if restitution of muscle tissue through protein synthesis was affected by varying the resistance of exercise for one group. Another sub-purpose was to determine if the varying of resistance had a different effect for skilled subjects as opposed to unskilled subjects in terms of increase in power output of the knee extensor/hip flexor muscles.

The pre-test involved seven measurements: 1) assessment of lean body mass; 2) measurement of maximal isometric force of the quadriceps muscles at an angle of 65°; 3) measurement of dynamic leg strength by use of a Cybex II isokinetic dynamometer at 30°/sec; 4) measurement of power output of quadriceps muscles by use of a Cybex II at 180°/sec; 5) measurement of power output of quadriceps muscles by use of a power rack and force platform; 6) measurement of power output of quadriceps muscles from vertical jump; and 7) measurement of vertical jump height.

In order to assign subjects to groups the individuals were classified as either skilled or unskilled in vertical jump. Each classification was ranked for power output by the results of pre-test measurements four to six. The eight top-ranked subjects were deemed high power and the six bottom-ranked subjects were deemed low power. The high powered subjects were first to be assigned randomly to treatment groups and then the low powered subjects were assigned randomly to treatment groups. This eventuated six high powered subjects and four low powered subjects in each training group. The control group had four high powered and four low powered subjects.

The three treatment groups were:

1) URG - uniform resistance group who trained with a heavy resistance five days per week for six weeks.

2) VRG - varying resistance group who trained with a resistance sequence of heavy, light, medium, light, heavy for five days per week for six weeks.

3) Control - who did no resistance training during the six weeks.

The post-test followed the exact format as outlined for the pre-test. The results of the pre and post-test were analyzed by a three-way analysis of variance with Scheffe tests performed post hoc on significant (.05) F ratios.

The results showed no significant difference in power output between training groups either during the program or from pre-test to post-test. There were significant differences ($P < .05$) for force production and velocity between the two training groups during the training program but they resulted in equal power output. There was some evidence to indicate a differentiation between the two training groups for the type of muscle fiber recruited and trained.

The effects of varying resistance on restitution of the muscle tissue were nil over the six week training period in terms of effecting force output.

Skilled subjects improved more in tests involving vertical jump but unskilled subjects showed greater improvement in all other tests.

It is concluded that there is no significant quantitative difference in power output between the two training programs used in this study, but there is reason to believe that there may be a qualitative difference.

Restitution of muscle tissue through the process of protein synthesis has no effect on force output over a six week training period for the magnitude of resistances and intensities of training used in this study.

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# APPENDICES

APPENDIX N-IV t-TEST FOR AVERAGE TIME PER LIFT FROM POWER TEST ON FORCE PLATFORM DURING POST-TEST

# APPENDIX A

## ANTHROPOMETRIC DATA

| SUBJECT | HEIGHT (cm) | LEAN BODY MASS (kg) | BODY MASS (kg) | AGE (YEARS) |
|---|---|---|---|---|
| 1 | 178 | 71.6 | 72.7 | 20.7 |
| 2 | 196 | 73.7 | 79.3 | 20.1 |
| 3 | 185 | 65.1 | 69.1 | 17.9 |
| 4 | 191 | 79.8 | 84.2 | 21.8 |
| 5 | 196 | 75.4 | 88.9 | 18.1 |
| 6 | 196 | 76.9 | 86.5 | 19.5 |
| 7 | 185 | 76.0 | 76.8 | 22.5 |
| 8 | 183 | 76.7 | 80.3 | 21.9 |
| 9 | 173 | 59.0 | 69.0 | 18.3 |
| 10 | 170 | 63.7 | 79.4 | 24.4 |
| 11 | 175 | 65.8 | 71.9 | 21.6 |
| 12 | 185 | 72.5 | 77.3 | 21.8 |
| 13 | 196 | 77.1 | 85.6 | 18.8 |
| 14 | 170 | 57.6 | 69.7 | 19.5 |
| 15 | 165 | 62.3 | 67.7 | 19.8 |
| 16 | 173 | 64.8 | 71.4 | 20.8 |
| 17 | 178 | 68.4 | 76.1 | 18.7 |
| 18 | 185 | 63.5 | 76.2 | 20.8 |
| 19 | 188 | 77.6 | 81.9 | 20.1 |
| 20 | 201 | 77.4 | 83.9 | 21.0 |
| 21 | 178 | 58.7 | 61.9 | 18.0 |
| 22 | 183 | 77.5 | 84.8 | 23.0 |
| 23 | 180 | 71.7 | 75.8 | 21.0 |
| 24 | 180 | 69.2 | 73.0 | 19.4 |
| 25 | 185 | 67.4 | 69.9 | 20.8 |
| 26 | 191 | 70.2 | 76.3 | 21.6 |
| 27 | 191 | 79.3 | 85.5 | 22.7 |
| 28 | 183 | 74.4 | 80.5 | 26.6 |

APPENDIX B

RAW SCORES

| SUBJ. NO. | STATIC LEG STRENGTH* | | DYNAMIC LEG STRENGTH** | | POWER CYBEX 180°/SEC*** | | POWER FORCE PLATFORM*** | | POWER VERTICAL JUMP*** | | HEIGHT VERTICAL JUMP**** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PRE | POST | PRE | POST | PRE | POST | PRE | POST | PRE | POST | PRE | POST |
| 1 | 300.0 | 263.6 | 26.4 | 24.1 | 1.69 | 2.38 | 18.46 | 36.82 | 78.47 | 85.46 | 59.7 | 62.2 |
| 2 | 290.9 | 263.6 | 15.6 | 15.8 | 1.81 | 2.08 | 15.88 | 64.29 | 72.25 | 73.01 | 58.4 | 61.0 |
| 3 | 213.6 | 227.3 | 16.8 | 13.3 | 1.71 | 2.23 | 16.39 | 67.78 | 85.87 | 101.54 | 55.9 | 63.5 |
| 4 | 218.2 | 259.1 | 13.2 | 16.6 | 1.76 | 2.16 | 5.07 | 31.85 | 84.12 | 82.76 | 61.0 | 61.0 |
| 5 | 300.0 | 309.1 | 19.8 | 24.9 | 2.58 | 3.00 | 6.69 | 67.87 | 63.70 | 78.10 | 49.5 | 57.2 |
| 6 | 304.5 | 363.6 | 16.8 | 24.1 | 1.99 | 2.57 | 10.19 | 66.69 | 86.00 | 95.27 | 58.4 | 61.0 |
| 7 | 318.2 | 350.0 | 18.0 | 20.0 | 1.74 | 1.97 | 18.31 | 70.76 | 89.78 | 94.03 | 63.5 | 63.5 |
| 8 | 272.7 | 318.2 | 16.2 | 20.0 | 1.88 | 2.44 | 10.19 | 56.61 | 102.10 | 106.78 | 55.9 | 58.4 |
| 9 | 209.1 | 245.5 | 17.4 | 17.5 | 2.13 | 2.37 | 8.16 | 40.09 | 88.49 | 93.28 | 52.1 | 54.6 |
| 10 | 213.6 | 236.4 | 15.0 | 11.6 | 1.90 | 2.02 | 11.64 | 48.28 | 64.70 | 67.39 | 43.2 | 45.7 |
| 11 | 290.9 | 345.5 | 19.8 | 20.4 | 1.87 | 1.96 | 16.73 | 49.95 | 72.12 | 75.52 | 54.6 | 57.2 |
| 12 | 277.3 | 290.1 | 16.8 | 12.5 | 2.42 | 2.34 | 13.10 | 57.80 | 98.00 | 98.52 | 71.1 | 71.1 |
| 13 | 336.4 | 313.6 | 25.1 | 20.0 | 2.74 | 2.79 | 16.11 | 39.12 | 74.81 | 74.62 | 53.3 | 53.3 |
| 14 | 200.0 | 250.0 | 14.4 | 17.5 | 2.15 | 2.71 | 18.92 | 54.12 | 95.91 | 97.81 | 61.0 | 63.5 |
| 15 | 186.4 | 259.1 | 15.6 | 17.5 | 1.50 | 2.32 | 11.94 | 31.41 | 51.82 | 58.56 | 45.7 | 50.8 |
| 16 | 259.1 | 218.2 | 13.2 | 16.6 | 1.86 | 1.83 | 9.89 | 39.05 | 55.33 | 53.50 | 38.1 | 38.1 |
| 17 | 300.0 | 368.2 | 22.8 | 18.3 | 2.52 | 2.28 | 9.77 | 43.07 | 83.83 | 89.95 | 49.5 | 52.1 |
| 18 | 200.0 | 277.3 | 16.8 | 15.8 | 2.34 | 2.51 | 13.23 | 30.90 | 99.18 | 92.69 | 62.2 | 59.7 |

APPENDIX B (Continued)

| SUBJ. NO. | STATIC LEG STRENGTH* | | DYNAMIC LEG STRENGTH** | | POWER*** CYBEX 180°/SEC | | POWER*** FORCE PLATFORM | | POWER*** VERTICAL JUMP | | HEIGHT**** VERTICAL JUMP | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PRE | POST | PRE | POST | PRE | POST | PRE | POST | PRE | POST | PRE | POST |
| 19 | 295.5 | 290.9 | 15.6 | 18.8 | 2.27 | 1.68 | 12.41 | 29.18 | 91.32 | 92.32 | 64.8 | 64.8 |
| 20 | 286.4 | 290.1 | 22.2 | 21.6 | 1.87 | 1.80 | 13.83 | 25.87 | 69.29 | 76.61 | 53.3 | 58.4 |
| 21 | 227.3 | 213.6 | 12.0 | 10.0 | 2.18 | 2.32 | 11.66 | 15.26 | 73.42 | 74.71 | 57.2 | 57.2 |
| 22 | 300.0 | 295.5 | 22.8 | 16.6 | 2.16 | 2.10 | 13.29 | 27.46 | 94.35 | 90.05 | 58.4 | 55.9 |
| 23 | 290.9 | 313.6 | 16.2 | 20.8 | 2.07 | 2.36 | 13.13 | 31.07 | 85.26 | 83.23 | 58.4 | 58.4 |
| 24 | 263.6 | 250.0 | 18.0 | 20.0 | 2.09 | 2.20 | 8.76 | 9.05 | 74.52 | 76.84 | 61.0 | 61.0 |

* kg

** kg m

*** Watts/kg LBM

**** cm

# APPENDIX C

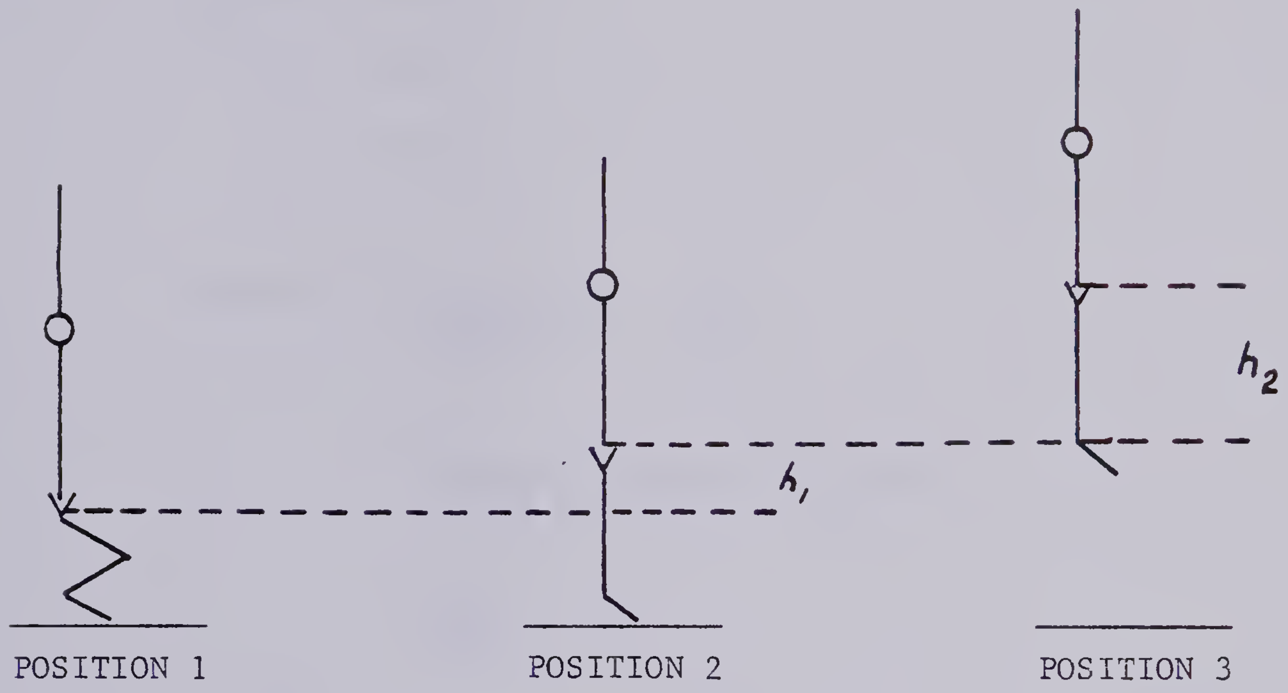
## CALIBRATION SHEET FOR FORCE PLATFORM AND POWER RACK ANGLE CORRECTION FACTOR

| CALIBRATION WEIGHT (LBS) | UNITS OF DEFLECTION | WEIGHT PER UNIT OF DEFLECTION | RANGE UNITS OF DEFLECTION | MULTIPLIER | CORRECTED FOR RACK ANGLE (- SIN 60$^{o}$) |
|---|---|---|---|---|---|
| 55 | 1.0 | 55.00 | 0 - 1 | 55.00 | 63.51 |
| 105 | 4.0 | 26.25 | 1 - 4 | 26.25 | 30.31 |
| 140 | 6.0 | 23.33 | 4 - 6 | 23.33 | 26.94 |
| 175 | 9.5 | 18.42 | 6 - 9.5 | 18.42 | 21.27 |
| 210 | 12.8 | 16.47 | 9.5 - 12.8 | 16.47 | 19.02 |
| 245 | 16.0 | 15.31 | 12.8 - 16.0 | 15.31 | 17.68 |
| 280 | 19.5 | 14.36 | 16.0 - 19.5 | 14.36 | 16.58 |
| 315 | 22.3 | 14.16 | 19.5 - 22.3 | 14.16 | 16.35 |
| 350 | 25.0 | 14.00 | 22.3 - 25.0 | 14.00 | 16.17 |
| 385 | 27.8 | 13.87 | 25.0 - 27.8 | 13.87 | 16.02 |
| 405 | 29.3 | 13.85 | 27.8 - 29.3 | 13.85 | 15.99 |
| 425 | 31.5 | 13.49 | 29.3 - 31.5 | 13.49 | 15.58 |
| 445 | 32.5 | 13.69 | 31.5 - 32.5 | 13.69 | 15.81 |
| 465 | 34.5 | 13.48 | 32.5 - 34.5 | 13.48 | 15.57 |
| 490 | 35.8 | 13.71 | 34.5 - 35.8 | 13.71 | 15.83 |

- Calibration weights were placed directly upon force platform.
- Units of deflection on graph were recorded for each weight increment.
- Weight/unit of deflection was calculated for each weight increment.
- Range of units of deflection was recorded for each weight increment.
- A multiplier number was calculated to correspond to each increment to give total force in lbs.
- Multiplier number was corrected for the angle of the rack and the lift by multiplying by Sin 60$^{o}$.

# APPENDIX D

## DETERMINATION OF POWER OUTPUT FROM VERTICAL JUMP




- $h_1$ is the difference between the starting position (1) and the completely extended position (2) measured from the center of gravity.
- $h_2$ is the height risen by the center of gravity from the extended position (2) to the peak of the jump position (3).
- The following formula is used for calculation of power:

$$\text{Power(in horsepower)} = \frac{w(h_1 + h_2)}{550\, h_1} \times \frac{gh_2}{2}$$

where:

$w$ = body weight

$h_1$ = vertical distance moved by center of gravity from position 1 to position 2

$h_2$ = vertical distance moved by center of gravity from position 2 to position 3

$g$ = acceleration of gravity (32 ft/sec$^2$)

APPENDIX D (Continued)

Example: Subject #3 (Pre-test)

Weight = 152 lbs.

$h_1$ = .46 ft.

$h_2$ = 1.83 ft.

$$\text{Power(hp)} = \frac{W(h_1 + h_2)}{550 \times h_1} \times \frac{gh_2}{2}$$

$$= \frac{152(.46 + 1.83)}{550 \times .46} \times \frac{32 \times 1.83}{2}$$

$$= \frac{348.1}{253} \times 5.41$$

$$= 7.49 \text{ hp}$$

To convert to Watts:

$$\begin{array}{rl} & 7.49 \quad \text{hp} \\ \times & \underline{746 \quad\quad} \ \text{Watts/hp} \\ & 5590.0 \ \text{Watts} \end{array}$$

To convert to power measure:

$$\div \ \frac{65.1}{85.87} \quad \begin{array}{l}\text{kg LBM} \\ \text{Watts/kg LBM}\end{array}$$

# APPENDIX E

## ONE-WAY ANOVA OF PRE-TEST SCORES

| DEPENDENT VARIABLE | SOURCE | SS | MS | DF | F | P |
|---|---|---|---|---|---|---|
| STATIC LEG STRENGTH | GROUPS | 0.220 | 11.00 | 2 | 0.01 | 0.994 |
| | ERROR | 0.447 | 2126.81 | 21 | | |
| DYNAMIC LEG STRENGTH | GROUPS | 0.229 | 1.14 | 2 | 0.07 | 0.928 |
| | ERROR | 0.322 | 15.31 | 21 | | |
| POWER CYBEX $180^{\circ}$/SEC | GROUPS | 0.300 | 0.15 | 2 | 1.63 | 0.220 |
| | ERROR | 0.194 | 0.09 | 21 | | |
| POWER FORCE PLATFORM | GROUPS | 0.127 | 6.35 | 2 | 0.43 | 0.653 |
| | ERROR | 0.307 | 14.61 | 21 | | |
| POWER VERTICAL JUMP | GROUPS | 0.320 | 159.97 | 2 | 0.80 | 0.462 |
| | ERROR | 0.419 | 199.75 | 21 | | |

# APPENDIX F-I

## ONE-WAY ANOVA OF POWER OUTPUT MEASUREMENTS DURING THE TRAINING PROGRAM

| SOURCE OF VARIATION | SS | DF | VARIANCE ESTIMATE |
|---|---|---|---|
| BETWEEN | 318.93 | 5 | 63.79 |
| WITHIN | 5446.87 | 54 | 100.87 |
| TOTAL | 5765.80 | 59 | |

$$F = \frac{S_b^2}{S_w^2} = \frac{63.79}{100.87} = 0.63$$

CRITICAL $F_{.05} = 2.38$

There is no significant difference ($P < .05$) for power output between the training groups during the training program.

# APPENDIX F-II

## ONE-WAY ANOVA OF AVERAGE TIME PER LIFT DURING THE TRAINING PROGRAM

| SOURCE OF VARIATION | SS | DF | VARIANCE ESTIMATE |
|---|---|---|---|
| BETWEEN | 1780 | 5 | 356.0 |
| WITHIN | 3365 | 54 | 62.3 |
| TOTAL | 5145 | 59 | |

$$F = \frac{S_b^2}{S_w^2} = \frac{356.0}{62.3} = 5.71$$

CRITICAL $F_{.05} = 2.39$

There is a significant difference ($P < .05$) in average time per lift between training groups during the training program.

SCHEFFE

CRITICAL $F_{.05} = 2.39$

$F^1 = (K - 1)\ F = 11.95$

| GROUP | COMPARISONS | F |
|---|---|---|
| I | II | 0.77 |
| I | III | 0.10 |
| I | IV | 5.89 |
| I | V | 0.10 |
| I | VI | 19.56* |
| II | III | 0.16 |
| II | IV | 2.92 |
| II | V | 0.32 |
| II | VI | 12.56* |
| III | IV | 3.29 |
| III | V | 0.00 |
| III | VI | 10.85 |
| IV | V | 4.73 |
| IV | VI | 1.40 |
| V | VI | 16.91* |

(Classification III - Table II)

*Significantly different ($P < .05$)

# APPENDIX F-III

## ONE-WAY ANOVA OF AVERAGE FORCE OUTPUT PER LIFT DURING THE TRAINING PROGRAM

| SOURCE OF VARIATION | SS | DF | VARIANCE ESTIMATE |
|---|---|---|---|
| BETWEEN | 420718 | 5 | 84143.6 |
| WITHIN | 115463 | 40 | 2886.6 |
| TOTAL | 536181 | 45 | |

$$F = \frac{S_b^2}{S_w^2} = \frac{84143.6}{2886.6} = 29.1$$

CRITICAL $F_{.05} = 2.45$

There is a significant difference ($P < .05$) in average force output per lift between training groups during the training program.

SCHEFFE

CRITICAL $F_{.05} = 2.45$

$F^1 = (K - 1)F = 11.95$

| GROUP | COMPARISONS | F |
|---|---|---|
| I | II | 3.30 |
| I | III | 0.00 |
| I | IV | 10.91 |
| I | V | 0.40 |
| I | VI | 39.91* |
| II | III | 2.36 |
| II | IV | 3.13 |
| II | V | 5.99 |
| II | VI | 20.26* |
| III | IV | 8.49 |
| III | V | 0.29 |
| III | VI | 28.50* |
| IV | V | 14.73 |
| IV | VI | 4.14 |
| V | VI | 48.29* (Classification III - Table II) |

*Significantly different ($P < .05$)

# APPENDIX G

## THREE-WAY ANOVA OF STATIC LEG STRENGTH

### ANALYSIS OF VARIANCE SUMMARY TABLE

BETWEEN SUBJECT FACTORS ARE:

A : 1 URG 2 VRG 3 CONTROL

B : 1 SKILLED 2 UNSKILLED

WITHIN SUBJECT FACTORS ARE:

C : 1 PRE-TEST 2 POST-TEST

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F | P |
|---|---|---|---|---|---|
| A | 777.208 | 2 | 388.604 | 0.112 | 0.894 |
| B | 121.117 | 1 | 121.117 | 0.035 | 0.854 |
| AB | 14794.715 | 2 | 7397.355 | 2.139 | 0.147 |
| S-WITHIN | 62260.000 | 18 | 3458.889 | | |
| C | 3770.667 | 1 | 3770.667 | 6.116 | 0.024 |
| AC | 603.670 | 2 | 301.835 | 0.490 | 0.621 |
| BC | 723.351 | 1 | 723.351 | 1.173 | 0.293 |
| ABC | 1423.963 | 2 | 711.982 | 1.155 | 0.337 |
| CS-WITHIN | 11097.000 | 18 | 616.500 | | |

# APPENDIX H

## THREE-WAY ANOVA OF DYNAMIC LEG STRENGTH

### ANALYSIS OF VARIANCE SUMMARY TABLE

BETWEEN SUBJECT FACTORS ARE:

A : 1 URG 2 VRG 3 CONTROL

B : 1 SKILLED 2 UNSKILLED

WITHIN SUBJECT FACTORS ARE:

C : 1 PRE-TEST 2 POST-TEST

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F | P |
|---|---|---|---|---|---|
| A | 0.817 | 2 | 0.409 | 0.016 | 0.984 |
| B | 0.516 | 1 | 0.516 | 0.020 | 0.889 |
| AB | 43.630 | 2 | 21.815 | 0.841 | 0.448 |
| S-WITHIN | 466.883 | 18 | 25.938 | | |
| C | 0.121 | 1 | 0.121 | 0.017 | 0.898 |
| AC | 9.730 | 2 | 4.865 | 0.682 | 0.518 |
| BC | 9.730 | 1 | 9.730 | 1.363 | 0.258 |
| ABC | 6.771 | 2 | 3.386 | 0.474 | 0.630 |
| CS-WITHIN | 128.477 | 18 | 7.138 | | |

# APPENDIX I

## THREE-WAY ANOVA OF POWER-CYBEX AT 180°/SEC.

### ANALYSIS OF VARIANCE SUMMARY TABLE

BETWEEN SUBJECT FACTORS ARE:

A : 1 URG 2 VRG 3 CONTROL

B : 1 SKILLED 2 UNSKILLED

WITHIN SUBJECT FACTORS ARE:

C : 1 PRE-TEST 2 POST-TEST

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F | P |
|---|---|---|---|---|---|
| A | 0.147 | 2 | 0.073 | 0.429 | 0.658 |
| B | 0.053 | 1 | 0.053 | 0.310 | 0.584 |
| AB | 0.124 | 2 | 0.062 | 0.361 | 0.702 |
| S-WITHIN | 3.080 | 18 | 0.171 | | |
| C | 0.407 | 1 | 0.407 | 10.048 | 0.005 |
| AC | 0.300 | 2 | 0.150 | 3.706 | 0.045 |
| BC | 0.038 | 1 | 0.038 | 0.933 | 0.347 |
| ABC | 0.077 | 2 | 0.038 | 0.947 | 0.406 |
| CS-WITHIN | 0.729 | 18 | 0.041 | | |

SCHEFFE FOR AC INTERACTION

| CELL MEAN COMPARISONS** | | F |
|---|---|---|
| I | II | 7.68* |
| III | IV | 0.93 |
| V | VI | 0.00 |

CRITICAL $F_{.05} = 3.47$

$F = (K - 1)F = 6.94$

* Significant ($P < .05$)

** Only cell means that are of practical meaning are included in the comparisons.

# APPENDIX J

## THREE-WAY ANOVA OF POWER-FORCE PLATFORM

### ANALYSIS OF VARIANCE SUMMARY TABLE

BETWEEN SUBJECT FACTORS ARE:

A : 1 URG 2 VRG 3 CONTROL

B : 1 SKILLED 2 UNSKILLED

WITHIN SUBJECT FACTORS ARE:

C : 1 PRE-TEST 2 POST-TEST

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F | P |
|---|---|---|---|---|---|
| A | 2055.340 | 2 | 1027.670 | 10.250 | 0.001 |
| B | 24.968 | 1 | 24.968 | 0.249 | 0.624 |
| AB | 39.405 | 2 | 19.702 | 0.197 | 0.823 |
| S-WITHIN | 1804.605 | 18 | 100.256 | | |
| | | | | | |
| C | 9170.086 | 1 | 9170.086 | 122.194 | 0.001 |
| AC | 1900.892 | 2 | 950.446 | 12.665 | 0.001 |
| BC | 8.841 | 1 | 8.841 | 0.118 | 0.735 |
| ABC | 54.560 | 2 | 27.280 | 0.364 | 0.700 |
| CS-WITHIN | 1350.813 | 18 | 75.045 | | |

SCHEFFE FOR AC INTERACTION

| CELL MEAN COMPARISONS** | | F |
|---|---|---|
| I | II | 105.51* |
| III | IV | 34.94* |
| IV | VI | 5.54 |

CRITICAL $F_{.05} = 3.47$

$F = (K - 1)F = 6.94$

* Significant ($P < .05$)

** Only cell means that are of practical meaning are included in the comparisons.

# APPENDIX K

## THREE-WAY ANOVA OF POWER-VERTICAL JUMP

### ANALYSIS OF VARIANCE SUMMARY TABLE

BETWEEN SUBJECT FACTORS ARE:

A : 1 URG 2 VRG 3 CONTROL

B : 1 SKILLED 2 UNSKILLED

WITHIN SUBJECT FACTORS ARE:

C : 1 PRE-TEST 2 POST-TEST

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F | P |
|---|---|---|---|---|---|
| A | 423.670 | 2 | 211.835 | 0.549 | 0.587 |
| B | 0.239 | 1 | 0.239 | 0.001 | 0.980 |
| AB | 558.431 | 2 | 279.215 | 0.723 | 0.499 |
| S-WITHIN | 6950.063 | 18 | 386.115 | | |
| C | 84.255 | 1 | 84.255 | 7.048 | 0.016 |
| AC | 81.144 | 2 | 40.572 | 3.394 | 0.056 |
| BC | 2.154 | 1 | 2.154 | 0.180 | 0.676 |
| ABC | 9.814 | 2 | 4.907 | 0.410 | 0.669 |
| CS-WITHIN | 215.188 | 18 | 11.955 | | |

# APPENDIX L

## THREE-WAY ANOVA OF VERTICAL JUMP HEIGHT

### ANALYSIS OF VARIANCE SUMMARY TABLE

BETWEEN SUBJECT FACTORS ARE:

A : 1 URG 2 VRG 3 CONTROL

B : 1 SKILLED 2 UNSKILLED

WITHIN SUBJECT FACTORS ARE:

C : 1 PRE-TEST 2 POST-TEST

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F | P |
|---|---|---|---|---|---|
| A | 143.393 | 2 | 71.696 | 0.809 | 0.461 |
| B | 284.182 | 1 | 284.182 | 3.208 | 0.090 |
| AB | 176.829 | 2 | 88.414 | 0.998 | 0.388 |
| S-WITHIN | 1594.313 | 18 | 88.573 | | |
| C | 22.066 | 1 | 22.066 | 8.913 | 0.008 |
| AC | 13.838 | 2 | 6.919 | 2.795 | 0.088 |
| BC | 0.209 | 1 | 0.209 | 0.085 | 0.774 |
| ABC | 5.655 | 2 | 2.827 | 1.142 | 0.341 |
| CS-WITHIN | 44.563 | 18 | 2.476 | | |

# APPENDIX M-I

## ONE-WAY ANOVA OF THE DIFFERENCE IN MEAN POWER OUTPUT BETWEEN TRAINING GROUPS FROM HEAVY-LIGHT SEQUENCE AS OPPOSED TO LIGHT-HEAVY SEQUENCE

| SOURCE OF VARIATION | SS | DF | VARIANCE ESTIMATE |
|---|---|---|---|
| BETWEEN | 56.25 | 1 | 56.25 |
| WITHIN | 38.88 | 10 | 3.89 |
| TOTAL | 94.63 | 11 | |

$$F = \frac{S_b^2}{S_w^2} = \frac{56.25}{3.89} = 14.46$$

CRITICAL $F_{.01} = 10.04$

There is a significant difference ($P < .01$) in mean power output between training groups from heavy-light sequence as opposed to light-heavy sequence.

# APPENDIX M-II

## ONE-WAY ANOVA OF THE DIFFERENCE IN MEAN FORCE OUTPUT BETWEEN TRAINING GROUPS FROM HEAVY-LIGHT SEQUENCE AS OPPOSED TO LIGHT-HEAVY SEQUENCE

| SOURCE OF VARIATION | SS | DF | VARIANCE ESTIMATE |
|---|---|---|---|
| BETWEEN | 41068 | 1 | 41068 |
| WITHIN | 6392 | 10 | 639 |
| TOTAL | 47460 | 11 | |

$$F = \frac{S_b^2}{S_w^2} = \frac{41068}{639} = 64.27$$

CRITICAL $F_{.01} = 10.04$

There is a significant difference ($P < .01$) in mean force output between training groups from heavy-light sequence as opposed to light-heavy sequence.

## APPENDIX M-III

ONE-WAY ANOVA OF THE DIFFERENCE IN MEAN TIME PER LIFT BETWEEN TRAINING GROUPS FROM HEAVY-LIGHT SEQUENCE AS OPPOSED TO LIGHT-HEAVY SEQUENCE

| SOURCE OF VARIATION | SS | DF | VARIANCE ESTIMATE |
|---|---|---|---|
| BETWEEN | 0.0606 | 1 | 0.0606 |
| WITHIN | 0.0316 | 10 | 0.00316 |
| TOTAL | 0.0922 | 11 | |

$$F = \frac{S_b^2}{S_w^2} = \frac{0.0606}{0.00316} = 19.18$$

CRITICAL $F_{.01} = 10.04$

There is a significant difference ($P < .01$) in mean time per lift between training groups from heavy-light sequence as opposed to light-heavy sequence.

APPENDIX N-I

t-TEST FOR FORCE OUTPUT FROM POWER TEST ON FORCE PLATFORM DURING PRE-TEST

| URG | | VRG | |
|---|---|---|---|
| $N$ = | 10 | $N$ = | 7 |
| $X$ = | 2010.2 | $X$ = | 1466.6 |
| $\bar{X}$ = | 201.0 | $\bar{X}$ = | 209.5 |
| $X^2$ = | 416202 | $X^2$ = | 314335 |

$$S^2 = \frac{\sum^{N_1} X^2 - (\sum^{N_1} X)^2/N_1 + \sum^{N_2} X^2 - (\sum^{N_2} X)^2/N_2}{N_1 + N_2 - 2}$$

$$S^2 = \frac{416202 - (2010.2)^2/10 + 314335 - (1466.6)^2/7}{10 + 7 - 2}$$

$$S^2 = 1278.1$$

$$t = \frac{209.5 - 201.0}{\sqrt{1278.1/10 + 1278.1/7}}$$

$$t = .48$$

critical $t_{.05}$ for 15 df = 2.131

There was no significant difference ($P < .05$) for force output from the power test on the force platform as measured during the pre-test.

APPENDIX N-II

t-TEST FOR AVERAGE TIME PER LIFT FROM POWER TEST
ON FORCE PLATFORM DURING PRE-TEST

| URG | | | VRG | | |
|---|---|---|---|---|---|
| N | = | 10 | N | = | 7 |
| X | = | 8.26 | X | = | 4.21 |
| $\bar{X}$ | = | 0.82 | $\bar{X}$ | = | 0.601 |
| $X^2$ | = | 7.57 | $X^2$ | = | 2.57 |

$$s^2 = \frac{\sum^{N_1} X^2 - (\sum^{N_1} X)^2/N_1 + \sum^{N_2} X^2 - (\sum^{N_2} X)^2/N_2}{N_1 + N_2 - 2}$$

$$s^2 = \frac{7.57 - (8.26)^2/10 + 2.57 - (4.21)^2/7}{15}$$

$$s^2 = .05$$

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{s^2/N_1 + s^2/N_2}}$$

$$t = \frac{0.826 - 0.601}{\sqrt{.05/10 + .05/7}}$$

$$t = 2.14$$

critical $t_{.05}$ for 15 df = 2.131

There was a significant difference ($P < .05$) for average time per lift from the power test on the force platform as measured during the pre-test.

# APPENDIX N-III

## t-TEST FOR FORCE OUTPUT FROM POWER TEST ON FORCE PLATFORM DURING PRE-TEST

| URG | | | VRG | | |
|---|---|---|---|---|---|
| $N$ | = | 10 | $N$ | = | 7 |
| $X$ | = | 3589.0 | $X$ | = | 2403.2 |
| $\overline{X}$ | = | 358.9 | $\overline{X}$ | = | 343.3 |
| $X^2$ | = | 1300739 | $X^2$ | = | 840706 |

$$S^2 = \frac{\sum^{N_1} X^2 - (\sum^{N_1} X)^2/N_1 + \sum^{N_2} X^2 - (\sum^{N_2} X)^2/N_2}{N_1 + N_2 - 2}$$

$$S^2 = \frac{1300739 - (3589)^2/10 + 840706 - (2403.2)^2/7}{15}$$

$$S^2 = 1886.7$$

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{S^2/N_1 + S^2/N_2}}$$

$$t = \frac{358.9 - 343.3}{\sqrt{1886.7/10 + 1886.7/7}}$$

$$t = .73$$

critical $t_{.05}$ for 15 df = 2.131

There was no significant difference ($P < .05$) for force output from the power test on the force platform as measured during the post-test.

APPENDIX N-IV

t-TEST FOR AVERAGE TIME PER LIFT FROM POWER TEST ON FORCE PLATFORM DURING POST-TEST

| URG | VRG |
|---|---|
| $N = 10$ | $N = 7$ |
| $X = 2.98$ | $X = 2.10$ |
| $\bar{X} = .298$ | $\bar{X} = 0.30$ |
| $X^2 = 0.8998$ | $X^2 = 0.637$ |

$$s^2 = \frac{\sum^{N_1} X^2 - (\sum^{N_1} X)^2/N_1 + \sum^{N_2} X^2 - (\sum^{N_2} X)^2/N_2}{N_1 + N_2 - 2}$$

$$s^2 = \frac{.8998 - (2.98)^2/10 + .637 - (2.10)^2/7}{15}$$

$$s^2 = .0013$$

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{s^2/N_1 + s^2/N_2}}$$

$$t = \frac{.3 - .298}{\sqrt{.0013/10 + .0013/7}}$$

$$t = .11$$

critical $t_{.05}$ for 15 df = 2.131

There was no significant difference ($P < .05$) for average time per lift from the power test on the force platform as measured during the post-test.